If We Can Cycle to Places, Do We Still Drive: Investigating Transport Accessibility and Annual Car Travel

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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Master of Planning.

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The purpose of this dissertation was to establish if people drive more or less in high and low accessibility areas and what it means for both policy and car orientated travel behaviour. Car dominance has been established in New Zealand with accessibility orientated policy having the potential to change this and reduce our reliance on the private vehicle. After reviewing relevant literature, it was established that research regarding accessibility had been well established both in New Zealand and internationally. However, comparing active mode accessibility to VKT has not been done spatially. Therefore, there is an opportunity to investigate the spatial correlation between accessibility and VKT and to discuss the implications it will have on transport policy and describing behaviour. To do so a spatial assessment using ArcGIS of both VKT and active mode accessibility was conducted. Active mode accessibility was assessed using a four-kilometre service area buffer to key locations including; primary schools, secondary schools, tertiary education, hospitals, health centres, supermarkets and employment. Annual VKT was assessed using the WoF dataset and only the year 2017 and 2018 and private vehicles were of interest. Car ownership rates were applied to VKT to calculate the annual VKT per person. Both accessibility and annual VKT were compared using area units. Results showed accessibility being greatest within the CBD and becoming increasingly poor further out. The correlation between accessibility and median annual VKT was 0.39, and the correlation between median annual VKT per person was 0.56. Accessibility results were consistent with other literature. Compared to other literature both correlations were strong. Overall people located in accessible areas do drive less; however, there are areas where this is not the case. A quantitative analysis of behaviour in areas identified to not follow the overall trend should be conducted. Accessibility focus policy should be applied with caution.

Keywords: Transport; Accessibility; Vehicle Kilometres Travelled; Car Usage; Cycling; Christchurch; Assessment; Transport Policy; Travel Behaviour.

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Chapter 1

Introduction

The private vehicle within New Zealand has shaped the way our cities and towns have been developed, and how we interact with them and current development is still aligned with the convenience of the private vehicle remaining a key driver of change (Mandic et al., 2019). Active mobility infrastructure has been established in urban developed areas including large investments into cycle lanes, paths and footpath upgrades; however, this has not been at the expense of private vehicles. Proof of this is New Zealand's vehicle fleet with private vehicles making up 78% of the trips people make and 91% of the kilometres travelled (Ministry of Transport, 2017). This raises the question of whether our reliance on the private vehicle is due to the way our cities are planned and developed or if it is our choice to use them even when not required. This question can be addressed by looking at a person's access via alternative modes to a car within an area and cross comparing this to how often people use their vehicles. Transport accessibility is a broad term that can have various meanings such as; access to certain transport infrastructure such as bike paths, access to vehicles or access to the locations we visit the most. For the purpose of this dissertation transport accessibility refers to the access to key locations, as measured by distance. A better understanding of accessibility can guide policymakers to make better-informed decisions on where development should occur and what policies need to be implemented to promote alternative transport modes (Abley & Halden, 2013). Having high accessibility is linked with reducing environmental impacts by reducing transport energy consumption as accessibility to sustainable modes (such as walking and cycling) reduces impact (Inturri et al., 2017). The other key component of this research is measuring private vehicle use. The use of a private vehicle and household travel patterns can both be measured and explained using Vehicle Kilometres Travelled (VKT) (Yamamoto et al., 2018). VKT can be used to measure the actual travel behaviour of people and can be contrasted with accessibility to determine if those living in accessible areas for alternative modes still predominately use the car.

This research intends to assess both walking and cycling accessibility within Christchurch at a property level and to identify car usage through VKT using the Warrant of Fitness (WoF) dataset. Both accessibility and VKT results will be correlated to identify their relationship as presumably, areas with higher accessibility should have lower car usage as it is more convenient to travel to locations. Results from the research can be used by transport policymakers to identify areas of concern or importance and looks at car usage behaviour.

1.1 Context

Transport policy is a major driver for encouraging people to use certain modes by hindering or enabling certain modes. In the Western world, increasing active transport is becoming a key objective of many policies and plans (Vale, Saravia & Pereria, 2016). Transport policy influences people's behaviour. There are many factors beyond key destinations that influence accessibility such as; demand for transport, service quality, affordability, user information, comfort, gender, household size, well-being, parking availability and fuel price sensitivity (Litman, 2019; Yamamoto et al., 2018; Vale, Saravia & Pereria, 2016; Handy & Clifton, 2001; Saghapour, Moridpour & Thompson, 2016). It is important to establish the motivations, context and reasoning for this research being carried out. The focus of this section will be around policy and providing background information, how policy applies to accessibility and looking at potential policy suggestions. This will be refined into three sections case background, accessibility policy and potential policy.

1.1.1 Background

In New Zealand, the private vehicle is the primary focus for transportation planning where planning documents especially district plans focus predominantly on concerns of the private vehicle such as car parking requirements, vehicle accesses and car trip rates. This is apparent in the district plans of the Greater Christchurch local authorities; Selwyn District Council (2018), Waimakariri District Council (2016) and Christchurch City Council (2018). The Selwyn District Plan (SDP) out of the three plans best recognises alternative transport modes through its objectives and policies. However, it also recognises that private motor vehicles are prioritised with car parking objectives and policies solidifying that. The SDP does not explicitly promote the use of private vehicles, instead accommodates their use for every possible trip. This is apparent in the rules and policies associated with vehicle accessways for private vehicle, pedestrian visibility orientated rules and having no maximum car parking requirement for developments. The Christchurch District Plan (CDP) similar to the SDP recognises that private vehicles are prioritised and has an objective relating to the promotion of public and active transport. However, the CDP attempts to promote a "one network approach" where all modes are provided for. The problem with the "one network approach" is that transport modes affect one another; this is apparent is the way cities are designed (Newman & Kenworthy, 2015). For example, most New Zealand cities are developed around the automobile, and when other modes are promoted, they struggle to be incorporated due to conflicting road use. The contrast between industrial and residential land use due to urban sprawl supports this. The Waimakariri District Plan (WDP) has significant car parking provisions. It is apparent that the car prioritised over other modes, as most rules are orientated towards the car and pedestrian safety from the car is factored heavily. Similar to the SDP and CDP there is a minimum requirement for car parking spaces.

1.1.2 Accessibility Policy

Litman (2019) discussed the concept of accessibility and how it can be incorporated into transport planning. Four major factors that impact transport accessibility were identified, including; travel conditions for motor vehicles, quality of other transport modes, network connectivity and land use proximity. This research will be focusing on accessibility concerning network connectivity (better connections results in more direct paths) and land use proximity (how close key destination are). Other factors that were considered by Litman (2019) as part of the final strategy recommendations included; affordability, demand for transport, options, mobility, information, integration, pricing and connectivity. Implications discovered by Litman (2019) for various road types and transport networks layouts (for example, single destination roads, grids and clustering) in the land use category were assessed. Litman (2019) concludes accessibility and mobility demand depends and varies with the quality of modal options available. Conventional mobility-based transportation planning should focus more on accessibility, and as many related factors tend to be overlooked despite their importance such as land use, integration of other modes and affordability (Litman, 2019).

Research conducted by Inturri et al. (2017) evaluated accessibility as a planning tool to reduce transport energy dependence in an urban area by evaluating land-use policies and integrated transport effectiveness. There were three strategies proposed to be used to reduce transport energy including; land use distribution, adopting measures encouraging transport modes with a low impact and promoting of efficient vehicles. In addition, four policy-based scenarios were produced and used, including; business, as usual, short-term transport policy, medium-long term transport policy, and long-term spontaneous land-use change. It was concluded by Inturri et al. (2017) that accessibility is a key part of social, environmental and economic sustainability success and is an indicator of environmental sustainability. This is true as high-density areas tend to have better transport accessibility options (especially alternative modes of transport) and travel less distance to reach destinations.

Abley & Halden (2013) conducted a spatial accessibility assessment for Christchurch and from this concluded that by better understanding accessibility there is the potential for improvement for how transportation and land use can be better managed and integrated. Improved understanding of accessibility also has the potential to guide policymakers to deliver improved accessibility both by clarifying current implicit accessibility policy and by setting out new explicit policies. Accessibility also needs to be considered as its own area of study, according to Abley & Halden (2013).

1.1.3 Potential Policy

Mandic et al. (2019) produced a report that studies the benefits of active transport and the current situation, ultimately making policy recommendations to promote active transportation in New Zealand. The methodology used consisted of investigating the benefits associated with active transport using relevant studies and data, whilst remaining consistent with the Treasury's Living Standards Framework and summarises the current levels of active transport. The framework incorporates four capitals; human, natural, social, and financial and physical. The main source of reoccurring data in the report was the New Zealand Household Travel Survey. It was concluded that between 1988 and 2014 the only mode of transport that increased was the car and the pressure to use cars over other transport modes continues to rapidly grow evidently by the number of kilometres driven by New Zealanders since 2013 (Mandic et al. 2019). Walking and cycling, as a result, is recognised to be decreasing overall. Despite this it was argued that almost two-thirds of car trips are within cycling distance (5 kilometres) and nearly one third are in walking distance (2 kilometres). The key point is that reducing distance may be a factor in encouraging active transport according to these findings.

Active transport was concluded to contribute to increased health outcomes and was specified to be essential to creating liveable spaces designed for people to enjoy and for social capital to be built. Mandic et al. (2019) state that using active transport routinely is fundamental to incorporating physical activity on a day to day basis. Although it is argued that car-focused urban form makes this increasingly difficult. There are four categories of policy supported by Mandic et al. (2019); the first being evaluation, governance and funding, the second consisting of education and encouragement promotion, the third is engineering (infrastructure, built environment), and lastly enforcement and regulation. Within these four categories, transport accessibility would fall within engineering, as accessibility is a measure of the built environment. Suggested policy options within Mandic et al. (2019) to increase accessibility includes; building and maintaining network of cycleways linking cities and suburbia, providing safe routes to schools which are located in reasonable walking distance, cycle parking provisions in district plans, 200 metre walkability to bus stops, integrating "complete streets" into the RMA, reducing speed limits (30 kilometres per hour zones in urban areas), car-free or reduced car zones in city centres and encourage new land developments to be high density to encourage active modes. Most of these policies are focused around improving or adding to existing infrastructure or making it more difficult for cars to be used incentivising active transport options. Improving infrastructure would improve active accessibility especially if more direct routes to key destination were established, where restricting car accessibility is more directed at travel behaviour aligning with reducing annual VKT.

1.1.4 Existing Annual Vehicle Kilometres Travelled (VKT) Data within Canterbury

Car dominance in New Zealand can be further explained by how many kilometres are travelled by car compared to other transport modes. This has been investigated through VKT analysis undergone by the Ministry of Transport (2019) in the form of the household travel survey. For context, the survey is completed by a sample of people logging their daily trips across 7 days and provides information on the number of trips, time spent travelling and most importantly for this research the number of kilometres travelled. This is done for the entirety of New Zealand and can be filtered by region. The most recent data is June 2014 as of 2019. According to the survey, people located in the Canterbury region travel 10,288 kilometres per year in a private vehicle, including both driver and passenger kilometres travelled. Compared to active modes, people within Christchurch travel 251 kilometres per year (181 kilometres walking and 70 kilometres cycling), significantly less than the car.

1.2 Objective

Based on the established context, accessibility plays an important role in transport policy and planning. Accessibility is the key to integrating land use planning within transport planning. By improving accessibility through reducing distances and better managing land use, active transport can be encouraged. Car dominance has been established in New Zealand with accessibility orientated policy having potential to change this and reduce our reliance on the private vehicle. The purpose of this research will be to establish a correlation between walking and cycling accessibility to identify if people actually drive more or less in high and low accessibility areas and to establish what this means for both policy and car orientated travel behaviour, with Christchurch used as a case study. This will be answered through identifying relevant literature to identify any gaps within the field, developing accessibility and VKT methodology for Christchurch, developing correlations between accessibility and VKT at a suburb level, and discuss results compared to the reviewed literature, transport policy and behaviour.

Chapter 2

Literature Review

2.1 Introduction

Active transport accessibility assessments and methods will be focused on when reviewing the following literature. The literature analysing vehicle usage will additionally be reviewed to grasp an understanding of what has been carried out and how it can be applied to accessibility. The following sections will be categorised by their relevance to the conducted research, starting with establishing an understanding of accessibility and ending with the most relevant literature to both accessibility and vehicle usage.

2.2 Defining Accessibility

It is important to establish what is meant by 'transport accessibility' as it is associated with many definitions. Ford et al. (2015) established transport accessibility as being the ease of access to key locations such as a place of employment or service from any location and has long been recognised as the key to sustainable transport, spatial and land use planning strategies. Abley & Halden (2013) had a similar definition of transport accessibility defining it as "the ease with which activities, either economic or social, can be reached or accessed by people" (p.g. 179). Litman (2019) perhaps offered the most simplified definition of transport accessibility stating that it refers to a person's ability to travel to activities, goods and services, recognising that this is ultimately the goal of transportation. In summary transport accessibility is the ease of access for a person to reach key locations such as goods, services and activities.

This research will be focusing on transport accessibility in its simplest form, specifically active mode accessibility (walking and cycling) by following the definitions established by Ford et al. (2015), Abley & Halden (2013) and Litman (2019) through the identification of distance to key locations in Christchurch. Some examples of key locations include supermarkets, doctors, hospitals, schools, recreation centres and places of employment (Abley & Halden, 2013). Based on this, Abley & Halden (2013) used eight key locations as part of the accessibility assessment, including; doctors, hospitals, primary schools, secondary schools, further education, convenience stores (including dairies and petrol stations), supermarkets and places of employment. These locations were established using the Social Exclusion Unit (2003) core trip purposes which were considered the most important for life chances. Recreation centres were the only location not considered by Abley & Halden (2013) which was identified by the Social Exclusion Unit (2003) and stated to include social, cultural and sporting activities. Although this can be broadened to include museums, galleries, bars, gyms, stadiums and event centres to meet the requirements of recreation centres, these are either not visited frequently or by enough of the population to have a large enough impact on the outcome of the accessibility assessment. Transport accessibility is perceived to follow a logarithmic pattern, where additional destinations to the key location shave a continuous reduced impact on overall accessibility. To put this into perspective the key locations are the destinations people travel to frequently, contributing to most distance travelled overall. Other locations will not be as visited as much as the key locations; therefore, it is assumed that if destinations that do not contribute to much to overall travel are added they will have an insignificant impact on the results.

2.3 Spatial Analysis to Assess Accessibility

Spatially analysing accessibility is the most established method of assessing accessibility based on the literature found. Both New Zealand based and international literature has been reviewed. Generally, literature has the same underlining method of accessibility assessment; the use Geographical Information Systems (GIS). The benefit of this is the ability to convey results visually, allowing for a larger audience to understand the results without having the required knowledge, although assessment methods can be complex and vary. In addition, many accessibility factors are geospatially orientated such as the location of key destinations, transport network and the potential movement of people. There is more than one way to measure accessibility using GIS, using different tools, processes and equations. A diverse range of methods within a GIS context will be reviewed.

Wagner (2003) conducted research into accessibility via alternative modes of transport to Christchurch's leisure centres. This was conducted by using GIS-Based modelling. The leisure centres of interest were the Pioneer Leisure Centre, Centennial Leisure Centre and QEII Park. The GIS methods used included using the average speed during peak and off-peak times to calculate the distance travelled in certain time intervals (5, 10 and 15 minutes), measuring the distances calculated along the transport network, and contrasting this with population density data to see how many people have access to the leisure centres (Wagner, 2003). It was concluded by Wagner (2003) that accessibly to Christchurch's main leisure centres varies significantly according to transport mode and traffic conditions, 40% of Christchurch's population is not within 15 minutes off-peak travel time to leisure centres (see Figure 2.1), with the car and bike being superior over walking and using the public transport regarding distance travelled.

Material Removed Due to Copyright Compliance

Figure 2.1 Accessibility Analysis of Leisure Centres within Christchurch showing Buffers for 5, 10 and 15 Minutes. Retrieved from Wagner (2003).

It is important to note that only three leisure centres were analysed and established at the time, which resulted in western suburbs such as Hornby, Avonhead and Yaldhurst not being accessible due to the spatial extent of the locations.

Research conducted by Cao (2008) focused on the Christchurch Central Business District (CBD) measuring the spatial accessibility effects of non-motorised transport and public transport to and from the central city to the rest of Christchurch. The study used pedestrian surveys to provide a general assessment of how accessibility influenced development in the central city. The accessibility assessment was conducted by converting average speed for walking and cycling into distances to find the distance travelled in 15, 25, 35 and 45 minutes respectively from a single point in the CBD. This methodology resembles the work of Wagner (2003) using speed as a measure of time and distance travelled. It was concluded that public transport and non-motorised transport modes are sustainable for future CBD development. Sustainability implied low energy and environmentally friendly transportation whilst still meeting growth demands within the city. However, cars still dominate trips to the CBD and existing bus services, walking and cycling serve inhabitants inadequately (Cao, 2008). Despite alternative modes connecting all parts of the inner city the problem lies with the inability to serve Greater Christchurch. It was determined by Cao (2008) that upgrades to the bus service, and active infrastructure will be required in future including the provision of bus lanes and more frequent services.

Abley & Halden (2013) aimed to define and measure accessibility in a New Zealand context using GIS methods. Maps were produced, indicating varying levels of accessibility from factors such as travel speed, distance, connections and travel direction. The basis of the method was to use distance and time to key locations (doctors, hospitals, primary schools, secondary schools, further education, convenience stores (including dairies and petrol stations), supermarkets and places of employment) and to weight them based on activity levels and population data for different age groups. Age, population and vehicles per household from 2006 was used and included as part of the analysis. Christchurch City Council (CCC) and Environment Canterbury (ECan) data used to create a Christchurch city-wide walking network. After the accessibility assessments were produced, the final scored accessibility assessment was used for assessing certain scenarios. The scenarios examined were used to understand the change in accessibility with changes in land use and the transport network. This included measuring the change in accessibility regarding altering land use (e.g. a new hospital) and the altering accessibility with the addition of new infrastructure (e.g. a new multi-modal bridge).

Wang, Han & de Vries (2018) investigated the relationship between land-use types and transport characteristics. The area of the study was within Eindhoven, a city located in the Netherlands. Zones were created using GIS and contained a single land-use type. This involved clustering similar land-use types together. Driving accessibility, cycling accessibility and walking accessibility were quantified based on the transport characteristics of each zone. Data used for the transportation network to identify transport characteristics were obtained from Open Street Map (OSM), and land use cover data for the zones were obtained from the Dutch Land Registry. Wang, Han & de Vries (2018) concluded that residential and commercial areas are in high accessibility clusters for all types of accessibility whilst industrial areas often only have adequate driving accessibility. Clustered land use maps and accessibility patterns can identify gaps in mobility service coverage and inefficiency of land use patterns (Wang, Han & de Vries, 2018).

Hyde & Smith (2017) conducted research for the New Zealand Transport Agency (NZTA) intending to explore the elements that influence transport value and to develop a framework that can be extended to the NZTA economic evaluation procedures to consider the contribution of isolated services to the wider network value. Value in this context is benefits to the transport network that are beyond financial such as efficiency and utility. Hyde & Smith (2017) also conducted an assessment using a ‘level-of-service’ type approach to measure social impact and accessibility. Level of service refers to how well a user of a transport mode is accommodated for regarding the transport infrastructure. For example, a road with a cycle lane will offer a higher level of service than a road with no cycle lanes. Census data was used to measure the level of service, along with GIS and statistical analysis to identify trends and relationships regarding accessibility and the future needs of the transport network. Hyde & Smith (2017) determined that including accessibility into the value of low-volumes services to the network was not well understood.

Research conducted by Handy & Clifton (2001) aimed to identify factors that contribute to accessibility at the neighbourhood level and to explore the different ways that planners can evaluate accessibility within neighbourhoods drawing on literature to do so. It was determined that two strategies were suitable to evaluate accessibility for neighbourhoods and to create a neighbourhood specific approach that builds a detailed accessibility database (Handy & Clifton, 2001). These two strategies are; a city-wide approach using GIS (evaluating accessibility for neighbourhoods across the city) and a neighbourhood specific approach (building a detailed accessibility database). Both strategies were evaluated using relevant literature. Accessibility was measured using a variety of transportation factors including; impedance (difficulty to travel to a destination), level of service (accommodating infrastructure for the mode), parking (availability and cost) and comfort factors (e.g. weather, traffic levels and vehicle conflicts). It was concluded by Handy & Clifton (2001) that the concept of neighbourhood accessibility provides a useful framework for the development of such a tool. When identifying accessibility factors, it is important to assess them based on their contribution to accessibility and examine their importance to residents, although no system has been undertaken to include these (Handy & Clifton, 2001). Identified factors vary from distance and cost to the condition of the environment and weather. The gap between the data that is needed to measure these factors and the data that is readily available demands a creative approach to measuring accessibility (Handy & Clifton, 2001). Although not specified by Handy & Clifton (2001), an example could be surveying residents asking accessibility focused questions and to show results spatially. What can be drawn from this literature is that the paper provides a starting point to pursue a GIS spatial analysis.

2.4 Active Accessibility Analysis

Although cycling accessibility is not a foreign concept in transport planning, it has been restricted due to the unavailability of travel data and limited research on cycling accessibility to key destinations based on distance (Saghapour, Moridpour & Thompson, 2016). The conducted research will focus on the accessibility of active modes, an understanding of the literature associated with active accessibility is, therefore, essential for the purposes of this research.

Saghapour, Moridpour & Thompson (2016) aimed to find a correlation between a cycling accessibility assessment and the number of bike trips within Melbourne, Australia. A key finding was that land-use diversity and non-motorised trips are both significant to each other regarding number of activities each type of land use offers. The methodology used was focused around using a service area and a cost matrix incorporating both travel distance and travel time. A service area is a distance from a point using the transport network, and a cost matrix is a table that ranks destinations based on travel time and distance. Census meshblocks were used as a measure for population and points of interest including; education centres, health and care facilities, community services, and retail and recreation centres. It was established that a four-kilometre service area buffer (distance from a given point using the transport network) was optimal for cycling distance. Travel time was also incorporated and analysed. Results showed that accessibility was greatest in the CBD for cycling and dispersed suburbs do not have a connection to the cycling network, thus have less cycling accessibility. Based on this result it was expected that the number of bicycle trips was to be reasonably high in the CBD. However, this was not the case as there were some suburbs that had a greater number of bicycle trips than the CBD. It was also determined that 50% of people have poor cycling accessibility within Melbourne. It was concluded from this that accessibility is complicated, with various other factors coming into play such as gender and wellbeing. For example, statistically women cycle less than men and wellbeing is often associated with physical ability. Despite this the accessibility analysis of the built and natural environment should not be ignored (Saghapour, Moridpour & Thompson, 2016). Overall the assessment was focused on assessing cycling accessibility over the bicycle trips which were clustered into suburbs making it difficult to cross compare to census meshblock accessibility.

Iacono, Krizek & El-Geneidy (2010) investigated issues related to developing accessibility measures for walking and cycling in Minneapolis and St. Paul, United States. The focus was on travel behaviour and land use to measure active mode accessibility. Travel behaviour was assessed through the number of people visiting a given location to determine if it is a preferred location. Data for this was recognised as limited. Travel survey data was used along with establishment data that assessed behaviour. The establishment data included information such as location sales, employees and industry classification. For measuring accessibility, GIS was the tool of choice with both travel time and distance impedance analysis (e.g. obstacles and barriers) being carried out. The article concluded that some direction is needed for future development regarding active accessibility measures and its applicability to transportation planning. Iacono, Krizek & El-Geneidy (2010) specified that in the past accessibility has been centred around space and time geography resulting in person-based accessibility measures. It is argued that this is critically important for accessibility research and travel behaviour since individual constraints can greatly affect a person's accessibility. It is also stated that there is a growing level of interest in active transportation modes, particularly in transportation policy and having robust transport accessibility measures can help form and evaluate land use transportation planning efforts. The article was focused on the measurement and evaluation of active mode accessibility not offering any comparison to any other statistical factors besides travel behaviour. Despite this it creates a framework for an accessibility assessment and what it could mean for transport policy.

The work of Vale, Saravia & Pereira (2016) was focused on extensively reviewing research published relating to the measurement of active accessibility. Reviewed literature was classified into four categories based on their methodologies used which included; distance-based, gravity-based, topological based and infrastructure. Distance-based is focused on assessing accessibility based on a person's proximity to destinations. Gravity-based accessibility uses the gravity model which weighs destinations based on the size of the opportunity (e.g. the number of visitors, students or people employed) and then calculates the cost of travelling there. Topological based accessibility is focused on the origin and destination of a trip incorporating topological characteristics such as slope and elevation. Infrastructure based is focused on the transportation-related infrastructure, such as the network and where activities specifically lie in relation to the network. Out of the 84 reviewed papers, 52 had cycling accessibility involved; however only 16 involved walking and cycling and only 6 were explicitly cycling. A criterion was used to evaluate accessibility measures from the reviewed literature. It was argued that active accessibility could be defined as the ability of an individual to reach relevant activities alone. This can be place and individual-based. Place-based, for example, is referring to a household, community or even a suburbs ability to reach relevant activities and individual is based on measuring an individual's ability to reach relevant activities. 18 papers used the methodology of the closest distance to each opportunity of each type with most using shortest distance analysis. However, the distance to multiple opportunities was the preferred methodology in some circumstances (calculated using a buffer surrounding a location). Weightings were incorporated in some cases and were used to rank the importance of locations. For example, not all locations will be as visited as often as others; therefore, a weighting is applied based on this. There are two methods for weightings; distance-based, and opportunity based (attractiveness). There is a huge variation in opportunity-based analysis (e.g. land use, area size, number of jobs) results. It was concluded by Vale, Saravia & Pereira (2016) that almost all methods have conceptual and computational limitations and inconsistencies in used terminology and concepts of accessibility. This is most likely due to diverse accessibility assessments resulting in difficulties capturing all variables in methodologies. Guidelines were established by Vale, Saravia & Pereira (2016) that might improve the consistency and value of active mode accessibility analysis. These include explaining accessibility variables used clearly (for example travel distance), defining any concepts surrounding accessibility, focusing more on cycling accessibility assessments and including slope as it is an influencer of route choices. Data collected from different sources makes methodologies hard to replicate. However, data limitations justify concerns over the accuracy of assessments. It was concluded from the findings that walking accessibility assessments had received more attention than cycling assessments which have received minimal attention. It was stated that the patterns of travel are becoming increasingly complex resulting in transport accessibility being increasingly important in explaining modal choice and travel behaviour. In addition, there are other variables suggested by Vale, Saravia & Pereira (2016) that are relevant to explaining travel behaviours such as parking availability and cost as these decrease the utility of car travel leading to an increase in walking and cycling.

2.4.1 Summary of Active Mode Accessibility

It can be established that the preferred methodology is by using spatial analysis, particularly through the use of a buffer. Distance travelled was more used than time with Saghapour, Moridpour & Thompson (2016) using a four-kilometre buffer and Vale, Saravia & Pereira (2016) covering mostly distance-based papers. Land use diversity and non-motorized trips are both significant to each other according to Saghapour, Moridpour & Thompson (2016). Active accessibility needs to be better understood in transport planning. Cycling accessibility is not well covered compared to other alternative modes such as walking and public transport. There are recognised to be other factors associated with active accessibility some directly related such as wellbeing, trips and visits and others not such as gender, parking availability and costs of other modes.

2.5 Vehicle Kilometres Travelled Analysis

All the literature reviewed so far has been focused on potential methodologies that could be used to measure accessibility, but none have compared accessibility to a variable such as VKT to investigate if people located in accessible areas drive more or less. Research investigating VKT needs to be identified as it is the other key component of this research to recognise car travel behaviour. The purpose of this section is to identify literature that uses VKT in the light of accessibility and active transport.

Yamamoto et al. (2018) applied a statistical model developed by Heitajan & Rubin (1990) to model VKT. Data for the model was from a study involving surveys of French households where different odometer ratings were recorded 1 year apart to determine annual VKT. Within the survey, there was also a reported VKT where respondents roughly estimate their personal VKT as they may not always be the driver of the vehicle. The adjusted model based on the work of Heitajan & Rubin (1990) was used to interpret and analyse these results. The use of VKT is supported by Yamamoto et al. (2018) specifying that it is a long-used indicator for measuring car use and travel patterns of households. It is also specified that there have been numerous studies that have used VKT with respect to gasoline consumption, vehicle emissions and exposure to road accidents. It was concluded that commuting cars have higher VKT but are used more frequently based on the number of trips. People located in low-density areas may have higher VKT readings as public transport options are generally limited. Another concluding point from the article is that periodic inspections for vehicles are trending in Europe which opens up the opportunity for more accurate VKT readings compared to surveys. New Zealand has already established this with the WoF inspection which will be the source of VKT readings for this dissertation.

Sullivan & O'Fallon (2010) conducted a report for NZTA aiming to provide better evaluations and monitoring of interventions (e.g. travel plans) in major urban areas (population exceeding 30,000) to reduce the distance travelled by car per person commuting focusing on active transport modes. It is assumed in travel plans that students and employees take the shortest route, and the research aims to determine whether this is accurate using the household travel survey results. A previous version of the household travel survey produced by the Ministry of Transport (2019) was the main source of data along with census data with 2006 being the latest used. Distance to work, distance to school and vehicle occupancy were assessed with recommendations provided. Both the median and mean values were assessed. The mean was used as an indicator for the plausibility of travel plans in terms of distance assumptions as there have been cases where travel surveys have incorrectly represented mean distance by including extreme values. To further address extreme values of VKT, the highest and lowest 5% of VKT readings were removed before the calculation of the mean at each end. This was conducted as outliers had a significant impact on the outcome. It was stated that the mean should be used with caution as extreme values can offset results significantly. Sullivan & O'Fallon (2010) concluded that the median distance travelled to work was 7.2 kilometres, and the mean distance was 10.2 kilometres. Census data showed that people are continually living further away from their place of work at a rate of 1% per year since 1996. The highest 1% of trips for school children are over 7 kilometres for cycling and over 5.1 kilometres for walking (2.9 kilometres for primary schools). Secondary school-aged children travel further. The actual distance travelled on average compared to the shortest path was concluded to be nine percent more compared to work-based travel plans.

A study conducted by Rendall, Page & Krumdieck (2015) provides insight into what is required from VKT spatial analysis using census and WoF datasets. The study aimed to measure oil vulnerability by using a combination of spatial data related to adaptability and maintainability which was; minimum and current transport accessibility (adaptability), and transport costs and income (maintainability). Using this data, a vulnerability assessment was created for Christchurch. This assessment was named the VIOLA (Vulnerability to Oil: Income, Land-Use and Accessibility) assessment. What was of most importance to this study is the use of WoF data. This was geocoded to calculate household VKT and fuel consumed to show spatially current energy costs. Rendall, Page & Krumdieck (2015) concluded that that the VIOLA assessment allows planners to analyse where, how and why affiliated residents are vulnerable tying into transport accessibility. The majority of areas in Christchurch were found to be adaptable. However, most areas spend 10% of their income on transport which leaves some areas considered less adaptable and vulnerable.

Kockelman (1997) investigated the significance between variables collated from both travel survey data and census data regarding vehicle miles and land use within the San Francisco Bay Area. Kockelman (1997) concluded that accessibility is very strongly associated with vehicle use through Vehicle Miles Travelled (VMT). The underlying theme of the study is the connection between travel behaviour and urban form in the shape of accessibility. The methodology incorporated density, accessibility and land use to model household VMT, vehicle ownership and mode choice. These were then broken down into multiple related dependent variables including total VMT per household, vehicle ownership and choice of transport (all retrieved from a travel survey). Other census related independent variables such as household size, age, sex, gender, income, population density were incorporated. Accessibility to jobs within a 30-minute radius by car walking and cycling was also looked at. All dependent variables (e.g. VMT, vehicle ownership and mode choice) were all correlated together in relation to the independent variables (e.g. accessibility and population density). The established relationships between dependent variables (VMT, vehicle ownership and mode choice) to the independent variable of accessibility are of the most interest. Transport choice was indicated in the travel survey by participants by stating whether they preferred the use of a private vehicle or walking and cycling. Kockelman (1997) concluded there is a strong relationship between accessibility and vehicle use. The reasoning behind the strong relationship is that the closer the opportunity is (accessibility), the lower the distance needed for the trip, hence reducing VMT and private vehicle dependence. There is also the indirect effect of accessibility being associated with higher land prices, less attractive parking opportunities and more traffic congestion (Kockelman, 1997). The article also stated that accessibility is a better predictor of VMT than population density, although population density is still highly useful when estimating vehicle ownership. Kockelman (1997) is the only literature that looks at the relationship between accessibility and VKT, although it is not spatial. It is important to understand how accessibility correlates with other variables, so conclusions relating to accessibility can be drawn.

2.6 Summary of Vehicle Kilometres Travelled Research

Research regarding accessibility has been well established both in New Zealand and internationally. A method for assessing accessibility can be established based on and supported by the reviewed literature. Many factors for accessibility within the literature are agreed upon, although some have more extensive methodologies than others. Spatial assessments to measure accessibility were the most common methodology used, and this research will follow that trend. It can be concluded that very few accessibility assessments explicitly investigated cycling and walking with most comparing all modes of transport for the purposes of a broader assessment. Research that relates to VKT to accessibility is limited which is prominently based on the reviewed literature which is less extensive than accessibility. Research into VKT and the evaluation of travel data has been carried out; however, there is an absence of incorporating it spatially as nearly all of the reviewed literature investigates VKT and travel data statistically. None of the reviewed studies looks at VKT and accessibility in New Zealand and although the WoF dataset has been used before it has not been applied to transport accessibility. Based on this there is an opportunity to investigate the spatial correlation between accessibility and VKT and to discuss the implications it will have on transport policy and describing behaviour.

Chapter 3

Research Question and Objectives

3.1 Research Question

This research will attempt to answer the following question:

“Do people living in high accessibility areas drive less, and what does this mean for both policy and car orientated travel behaviour?”

To be able to answer this question, a series of objectives will need to be addressed.

1. What areas are considered to have low or high cycling accessibility? – This will require an accessibility assessment to be conducted to determine areas within Christchurch with high and low cycling accessibility.

2. To calculate the amount of driving that people are doing at a census area unit level – This will be addressed by conducting a spatial assessment of geocoded WoF data using the odometer readings.

3. Is there a correlation between VKT and transport accessibility? –The results from both accessibility and VKT analysis will be correlated using statistical analysis.

There has been no research so far in New Zealand investigating the relationship between active accessibility and VKT. The proposed research aims to establish whether there is a correlation between active accessibility and VKT, to be able to explain if people in high and low accessible areas drive more or less. The results from this aim to provide information that can be used to inform policy initiatives and highlight car travel behaviour. It is important to note that this research does not aim to reduce VKT or improve transport accessibility as that is beyond the scope of this research. However, conclusions drawn from this research will aim to aid policy and decision-makers for future land use decisions and describe the current private vehicle use travel behaviour. The methodology can also be applied to other areas throughout New Zealand. If there is no correlation established for VKT and transport accessibility, then it can be established that accessibility cannot predict VKT and behaviour needs to be targeted through other means besides accessibility-related policy. If there is a correlation, policy should be directed towards improving accessibility to reduce private vehicle use.

Chapter 4

Methodology

4.1 Introduction

Based on the reviewed literature, an accessibility assessment can be conducted using the distance from where people live to key locations. The accessibility assessment will only be for active modes. The key location categories that will be used for the accessibility assessment are those established from Abley & Halden (2013), excluding convenience stores. This is due to multiple reasons, including convenience stores not being specific to active modes, data constraints and are non-primary trips. Abley & Halden (2013) assessed convenience stores because their assessment for accessibility was based on all modes, however since active modes will be assessed there is no need for petrol stations and dairies are considered minor trips. Convenience stores are non-specific locations covering a broad number of places such as petrol stations and dairies. Supermarkets cover the needs of a dairy and petrol stations are only relevant for motorised vehicles. Convenience stores are also considered as "pass-by" trips and therefore are not recognised as a key destination, which is the main reason for a trip. The distance used from the key locations will be four kilometres, which was used in Saghapour, Moridpour & Thompson (2016) for cycling distance. The purpose of this research is to look at areas where you do not have to use a car to get to key destinations and to compare this with how much people are driving to see if residents still use their car even when not required too. Therefore, it makes sense to investigate active accessibility in contrast to how much people are driving. Additionally, active modes generally have limited range which will allow for more diverse accessibility results allowing for a better comparison. Comparing the amount people drive to how accessible places are to the car offers no insight into driver behaviour if everything is considered accessible. This chapter will state the methods used to assess accessibility and VKT using spatial analysis.

4.2 Data

The accessibility assessment will be heavily reliant on key destinations, property locations and the transport network. VKT will require odometer readings from the WoF database. The sources for the required data are summarised in Table 4.1 below.

Table 4.1 Summarised information on the data used.

Key Data	Source	Data Entries/Features
Property Points	Land Information New Zealand (2019a)	2,256,854
Transport Network	Open Street Map (n.d.)	15,526
Primary Schools	Ministry of Education (2019a)	2,555 (including Secondary Schools)
Secondary Schools	Ministry of Education (2019a)	2,555 (including Primary Schools)
Tertiary Education	Ministry of Education (2019b)	444
Hospitals	Ministry of Health (2015)	83 (Public) 75 (Private)
Medical Centres	National Map (2019a)	85
Supermarkets	National Map (2019b)	40
Employment	Statistics New Zealand (2015)	2,012
Warrant of Fitness Data	New Zealand Transport Agency	4,194,300

Further detail regarding the data such as the details of the source, format and modifications to the data before processing will be explained. Most of the data required cleaning or exporting to another format to make it suitable for a spatial accessibility assessment.

4.2.1 Property Points

The property point layer in the form of a shapefile that was acquired from Land Information New Zealand (2019a) had no attribute fields that can distinguish the types of properties, for example a dwelling and industrial site. The reason for this is that the accessibility assessment is only interested in where people live, as the overall aim of the assessment is to identify a person's accessibility, not a place. Planning zones from Environment Canterbury (2019) were used containing zones such as open space, special purpose, industrial, commercial, rural, residential and mixed-use for the Canterbury Region. Only Christchurch planning zones were used as it is the area of interest. Zones considered to be inhabited were exported, which included residential, rural and mixed-use zones and excluded open space, industrial and commercial zones. The reasoning for this is that planning zones are on a property scale and are the most accurate source of information specifying land use. The exported inhabitable planning zones were used to identify what properties are theoretically inhabited. Properties that lie within these zones are assumed to be inhabited and were located using a search by location function. Property points were reduced to 157,381 for the accessibility analysis.

4.2.2 Transport Network

Open Street Map (OSM) centrelines were used, and although they did not have readable vehicle restrictions (i.e. one-way streets and no entry/exit) this it is not necessary when building the transport network. Since accessibility will only be assessed for active modes, the same vehicle restrictions as private vehicles do not apply due to cycleways, footpaths and crossings being used which are not subject to the same restrictions. Because of this, the transport network was built with no vehicle restrictions. The OSM data when downloaded needed to be cleaned by removing unnecessary and inapplicable infrastructure such as; raceways, service driveways, bus stops, construction and motorways. The extracted centrelines are not enough to create a working transport network. Firstly, intersections need to be recognised which requires the lines to be split where the lines intersect. This was done using the split line at vertices tool which splits the polylines at where they bend, curve and most importantly the where they intersect. The transport network was then created using ArcGIS. Default settings were used when creating the network. The only exception was the removal of the one-way vehicle restriction, as pedestrians and cyclist are not subject to this condition.

4.2.3 Primary and Secondary Schools

Data on schools was retrieved from the Ministry of Education (2019a) data service in the form of an excel spreadsheet containing information on both primary and secondary schools such as contact details, surrounding land use, type (used for classification), authority, role numbers and coordinates. Since the layer was downloaded as an excel spreadsheet, a spatial reference needed to be given to the data. This was carried out by using the X and Y coordinates for each of the schools listed. The X and Y fields corresponded to latitude and longitude fields and provided a spatial reference for each of the schools each representing a point.

After this was done, schools in Christchurch were selected and exported as they are the schools of interest. The next step in the process was to categorise the schools into primary and secondary so that two independent shapefiles could be exported. This was done by selecting points within the attribute table field which differentiated the schools from primary and secondary. There were multiple types of schools that needed to be reclassified into primary and secondary school categorisation. This was done by creating a new field within the attribute table, selecting the schools that needed to be reclassified and assigning them to be either primary, secondary or both in the new field.

Justification for the categorisation is as follows. Composite Schools accommodate for years 1 to 13 these schools were classified as both. Intermediate schools were classified as primary schools as most primary schools are full primary (accommodating years 1 to 8) as opposed to contributing (accommodating years 1 to 6). Secondary schools that accommodate years 7 to 13 will be classified as secondary schools as the majority of year groups are classified as a secondary school. Special schools and teen parent units will be excluded as they do not have enough students to consider and are a minority. Including these schools will be insignificant in the results. Once cleaned there were 161 primary schools and 42 secondary schools that will be used for the accessibility analysis.

4.2.4 Tertiary Education

Data for tertiary education was obtained from the Ministry of Education (2019b) data service in the form of an excel spreadsheet containing information on tertiary providers. The first step was to isolate the Christchurch tertiary education sites which conducted manually in the spreadsheet opposed to spatially due to the smaller dataset. The tertiary education directory did not have any X and Y coordinates for each of the tertiary providers required to create points, however since there are only 35 Christchurch tertiary education sites they were manually geocoded. This was done by using the addresses for each site to obtain usable X and Y coordinates. The coordinates from the addresses were added to the spreadsheet in the appropriate created X and Y columns. The coordinates were used to create spatial points for each tertiary provider within ArcGIS.

4.2.5 Hospitals

Data for hospitals was obtained from the Ministry of Health (2015) in the form of excel files. It was downloaded for both public and private hospitals which contained all hospitals for New Zealand. The same process as the tertiary data was conducted to convert the data into a usable shapefile. Both public and private hospitals were combined to make up 7 hospitals (5 public and 2 private) in total.

4.2.6 Medical Centres and Supermarkets

The locations of medical centres and supermarkets within Christchurch were retrieved from National Map (2019), a data service provider. Both data sources were separate shapefiles and did not require any cleaning to be used as part of the accessibility assessment. No points were added or deleted.

4.2.7 Employment

Employment data was retrieved from Statistics New Zealand (2015) and was manipulated from the commuter view raw data in an excel spreadsheet form. The data showed the number of people who commute to different census area units. This was calculated by Statistics New Zealand through people who recorded a workplace address during the 2013 census. For the purposes of the accessibility assessment, the number of people travelling between each area unit was not of interest. Instead it is the number of people working within each area unit. Due to this only the total number of people working in each area unit was used, and the spreadsheet was joined to the spatially referenced area units retrieved from Statistics New Zealand (2018). 119 census area units were used for the accessibility assessment.

4.2.8 Warrant of Fitness Data

Extensive cleaning was required to get the WoF data into a usable spatial format. The data included fields such as; vehicle ID, inspection key, inspection date, inspection type, odometer reading, odometer distance unit, costumer type, street address, vehicle type, vehicle make, vehicle model, motor type, vehicle year, CC rating and vehicle status. In total, there were 21 columns and 1,485,575 entries within each spreadsheet. The data was separated into 6-month periods for each spreadsheet and was for the entirety of New Zealand, covering all vehicle types. The data was filtered using a python script to select vehicles that were located in Christchurch, acquired warrants between 2017 and 2018 and were for private use. The script then proceeded to calculate the number of days between inspections and the difference between the odometer readings, to ultimately calculate the number of kilometres a given car travels per year giving the annual VKT.

There were some technicalities around the data; there had to at least two warrants acquired from the same vehicle during the 1st January 2017 and the 31st December 2018. This is so that the differences in VKT can be calculated. Due to this if there was only one warrant recorded for a vehicle, the script eliminated that reading. Vehicles that had acquired more than two warrants between 2017 and 2018 were dealt with by taking the difference between the first and last readings. This allows for a larger time period, in theory giving more accurate results as there is more data. Any odometer readings that had unknown units were eliminated, and any odometer readings recorded in miles were converted to kilometres. If a vehicle had changed its address since the first inspection, the latest address was used. There were a significant number of readings that were repeated. The script deleted one of these values and kept the other. A total of 51,491 WoF readings were outputted by the script.

By using a property spreadsheet acquired from Land Information New Zealand (2019b), the script output was geocoded using VLOOKUP in excel. This allowed for the coordinates from the property spreadsheet to be matched with the addresses from the script output. The coordinates were then used to represent the data spatially using ArcGIS. Any address that was not matched using VLOOKUP were excluded as these values appeared as “null” resulting in no point being created. Once this was carried out the data was then edited as there were some outliers within the data. If a point had inspections carried out less than week apart the point was deleted. If a point had an odometer difference of 0 or above 250,000 kilometres per year it was also deleted. Anything above 250,000 kilometres per year is seen as unrealistic. For example, to achieve 250,000 kilometres per year a vehicle would need to be travelling at least 685 kilometres every day of the year. To put this into perspective if someone was averaging 70 kilometres per hour it would take just under 10 hours to travel 685 kilometres which is unrealistic. Both geocoding and trimming processes reduced the number of points from 51,491 down to 49,320. The edited points were spatially joined to census area units with the merge rule for annual VKT set to median and mean respectively. Maps were produced showing both the mean and median annual VKT.

4.3 Accessibility

Christchurch is a flat city, allowing for topographic constraints to be disregarded in most cases. Distance will be used as it was concluded from the literature review to be just as viable as using time travelled for measuring accessibility. Using the transport network, service area buffers will be used as it is an accurate representation of distance travelled compared to using a linear buffer radius (surrounding straight line distance). Simply put, distance varies in a transport network based on the length of the roads and how direct they are to the desired location, a service area buffer compensates for this as it is very unlikely that a mode will be able to travel directly to the point in a straight line from a key destination. Accessibility will be assessed at a property level as the assessment will be focused on a person’s accessibility to key destinations. The cleaned property point layer will be used, and service area buffers will be created around each of the key destinations to find the number of properties within a four-kilometre radius. This will be the basis of the accessibility assessment.

4.3.1 Service Area Buffers

The service area buffers were created manually to verify if they would work using network analysis and the created road network. This process was somewhat automated by building a model using Model Builder (part of ArcGIS). This is essentially a flow chart which carries out the necessary steps and processes to create a service area buffer. This model can be found in Figure 4.1.

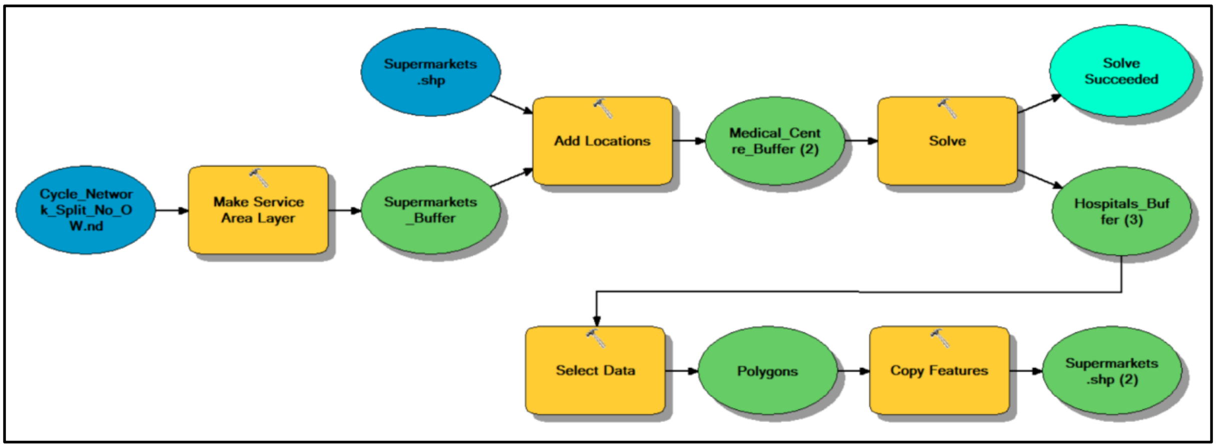

Figure 4.2 Model used to create the service area buffer within Model Builder.

Following the model from left to right, the road network is inputted and run through a service layer tool setting the parameters for the network buffers. Through this four-kilometre independent service area buffers are set to be created. Key destinations need to be added, so the model knows what points need to have the service areas around them creating service area buffers. This is where the appropriate locations (e.g. primary schools, secondary schools, tertiary education, hospitals, medical centres and supermarkets) were independently inputted through add locations. Once the locations have been added, a solve can be done which creates the service area buffers around the key locations inputted using the created transport network. The service layer polygons are selected and exported so they can be used for analysis. This is done through the Select Data and Copy Features tools, exporting the polygons as a shapefile.

4.3.2 Key Destinations

A spatial join was conducted to determine how many key locations are accessible to each property. A spatial join is a tool that joins two spatial datasets together based on their location. In this case, the property points were joined to the created service area buffers and were repeated six times for each key destination type. The tool produced a join count field which shows states the number of service area buffers each property falls within. Each output of the spatial join for each key destination was converted to an excel spreadsheet to be able to combine the join count fields. The join count fields for each key destination were combined and reimported into ArcGIS to make the data spatial again. Maps were produced based on the count fields showing the number of key locations accessible within four kilometres for each key location.

4.3.3 Employment

Employment accessibility was assessed differently due to the data only being available in area units and not in the form of points. This required a different methodology to be carried out with similarities for consistency purposes and to ultimately combine all key destinations accessibility together. Points were created using the area unit polygons by using a tool that made a point in the centre of the area unit. These points were then manually edited, so they are near the road network and in an area where there are likely to be places of employment (e.g. urban areas). Urban townships were targeted as opposed to rural developed areas as there is assumed to be a higher density of people employed in urban areas. Service area buffers were created around each of the created points. These were manually checked afterwards due to discontinuities in the road network (e.g. the road was not attached to the wider network). The number of employed people within four kilometres of each property needs to be identified. To do so the same methodology as the other key destinations were used by conducting a spatial join with the created area unit points. The field that represents the number of people employed for each buffer was summed during the spatial join. This is because the total number of people employed is of interest in each property location. A map was produced for the count of number of people employed with four kilometres.

4.3.4 Weightings

The base weightings for each of the accessibility destinations were extracted from Abley & Halden (2013) and are listed in Appendix E. Applying weightings are important as each age group will visit each key destination more or less frequently than others. For example, people aged 25-64 will visit work more than people aged 10-19 who are more likely to frequently visit a school. All key destination weightings were identical to the weighting used for cycling in Abley & Halden (2013) except for convenience stores for reasons previously established. The original weightings were adjusted to make up for the missing convenience store weighting. These were balanced as follows;

- For the 10-19 age group, the convenience store weighting was split evenly between the three highest other weightings; secondary school, tertiary education and employment.
- For the 20-24 age group, three quarters of the convenience store weighting was added to work, and the other quarter was added to further education.
- For both 25-64 and over 65 age groups, the convenience store weighting was added to work.

Only the weighting for the cycling mode were used and therefore did not always total to the same amount for each age group. The weightings are intended to be used as a ratio to split the key destination importance for each age group, thus having a round total value is not of importance. The final weightings for each age group can be found in Appendix A.

Not all age groups have the same amount of people within them; for example, there is a higher percentage of people aged 25-64 than people aged 0-4. Therefore, this needs to be accounted for by using population census data from Statistics New Zealand (2014). This was done using the same methodology as Abley & Halden (2013), where the census population data was used and applied to each of the adjusted weightings for each age group shown in Appendix A. Unlike Abley & Halden (2013) who used 2006 census data, 2013 census data was used. The process was carried out by retrieving census data from Statistics New Zealand (2014) for the Canterbury region. Only population data for the required age groups (0-4, 5-9, 10-19, 20-24, 25-64 and above 65) was used. Each age groups population data was converted into a percentage (using the total population) and applied to the weightings through multiplication to determine the impact of the weighting based on the population. Once this was done, the final weighting was calculated for each destination by summing each key location weightings for each age group together and was converted to a percentage. Further detail on this process can be found in Appendix A.

4.3.5 Relative Accessibility

Accessibility will be defined as being relative to the entire city in order to combine all key location accessibility results. If the counts were summed, there would be a disproportionate representation of key locations which had high counts. Therefore, relative accessibility is used to standardise all the results. It is difficult to set a limit for accessibility, for example if a location is accessible to x number of locations it is accessible. Relative accessibility was calculated using the median, minimum, maximum, lower quartile and upper quartile for each key locations accessibility results. The reason for this is that these values split the data up evenly based on the individual number of data points. If a property is not within any specific key location of interest it is assigned a value of 0, as it is inaccessible. If a property is between the minimum and lower quartile it is considered to have poor accessibility and assigned a rating of 1. If a property is between the lower quartile and the mean it is considered to have fair accessibility and assigned a rating of 2. If a property is between the mean and the upper quartile it is considered to have good accessibility and assigned a rating of 3. If a property is between the upper quartile and the maximum it is considered to have great accessibility and assigned a rating of 4. The higher the total weighting, the better the accessibility. Further detail on this can be found in Appendix A. The weightings were applied in ArcGIS. Properties were selected by the count values (number of key locations with four kilometres) and given the appropriate weighting based on the key locations assigned relative accessibility range. Once the weightings were applied to each key location, they were combined for each property to indicate the overall accessibility for all key locations. This process was carried out for all key destinations including employment opportunities to give a final accessibility weighting.

4.3.6 Applying the Weightings to Relative Accessibility

As determined by Abley & Halden (2013), not all trips to each of the key locations are of equal importance. Hence the calculated final key destination percentage weightings (described in Section

4.3.4) need to be applied to the calculated relative accessibility (described in Section 4.3.5). To do so each calculated relative accessibility rating will be multiplied by the relevant percentage weighting, to accurately show the importance of each key location relative to the Christchurch population. Since employment opportunities are in area unit form, the other key locations which are on a property scale will need to be upscaled to area units. This was done using a spatial join (join based on location) to census area units to ensure everything is conducted on the same scale. The percentage weightings for each key location excluding employment were applied prior to the spatial join as these were specific to each property, not each suburb. This was done by creating new fields for each location with the respective tables and multiplying the relative accessibility weighting with the percentage weighting. Each of these fields had a merge rule of 'mean' during the spatial join to get the average rating for each area unit. Only the multiplication of the relative accessibility weighting with the percentage weighting was carried out for employment opportunities as it was already in area unit form. All calculated fields were then summed to give a final accessibility score. A map was produced to show the final accessibility score. A correlation between accessibility and median annual VKT results was also conducted using excel.

4.3.7 Vehicle Ownership Rates

Vehicle ownership was incorporated into the VKT analysis to identify the annual VKT travelled per person. For example, a household within a highly accessible area may have four occupants and only one vehicle; the areas may have high annual VKT because that one vehicle is being used by four people. Due to this it is important to balance out the annual VKT with vehicle ownerships rates per person to identify the annual VKT travelled by car per person. Vehicle ownership rates per person were calculated using the Statistics New Zealand (2014) dataset and using; number of cars per household, number of households and the average residents per household. Since the dataset does not specify how many cars a household has beyond three, households that were stated to own three or more cars were considered to only own three cars. Once a value had been calculated for car ownership rates per person it was then applied to the annual VKT values by multiplying it with median VKT. This was done using the table join feature and field calculator in ArcGIS. The output was exported, and a correlation was established between car ownership adjusted VKT and cycling accessibility in excel. A map was produced showing the annual VKT per person.

Chapter 5

Results

Once the methodology was carried out, a cycling accessibility assessment and a VKT assessment of Christchurch was produced. This chapter will state the results from the accessibility assessment including an analysis of the relative number key destinations per property, both median and mean VKT results, a comparison of weighted accessibility and median VKT, and contrasting car ownership rates with median VKT. All names of area units are stated within Appendix B, otherwise referred to locations will be identified on the relevant maps.

5.1 Accessibility

Since the accessibility assessment was based on access to key locations, each key location had an independent accessibility assessment carried out prior to being weighted. All assessments follow the general pattern of becoming increasingly accessible towards the CBD, although there is slight variation in the assessments. This will be looked at in further detail using the actual number of location accessible to each household without any applied weightings. Any properties that have significantly different results in comparison to surrounding properties is due to road network issues where parts are detached or do not link up with key destinations.

5.1.1 Primary Schools

Primary schools were the most abundant of the key destinations, hence being the most accessible to properties. Figure 5.1 shows the focal point of primary schools being Merivale and the most accessible properties being located in Bryndwr, Fendalton, Papanui, Riccarton and the lower CBD. The accessibility coverage for primary schools is extensive in particular the East and South East of Christchurch with properties still being relatively accessible on the fringes of Prebbleton and Hornby. This coverage is not replicated for the northern Suburbs of Christchurch as both Parklands and Belfast are relatively inaccessible.

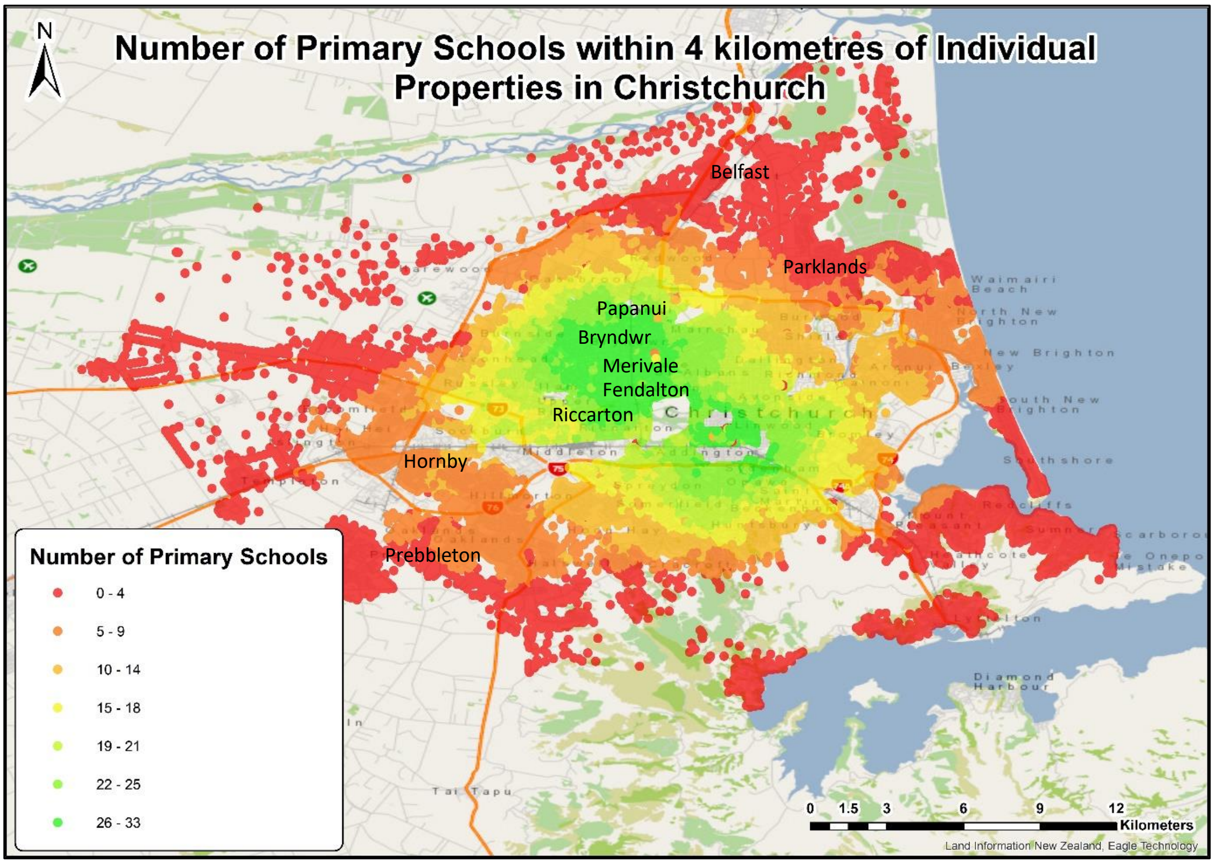

Figure 5.1 Number of primary schools within 4 kilometres of each property.

5.1.2 Secondary Schools

Accessibility to secondary schools varies from the trend of accessibility being exclusively the best in the CBD, as there are three clusters of high accessibility elsewhere, including the CBD as shown in Figure 5.2. These clusters are located in Riccarton, St Albans and south of the CBD covering west Linwood and Addington. Similar to primary schools, the extent of accessibility extends to part of Prebbleton. There is a large area of properties that are accessible to four to five secondary schools extending from Papanui to Casebrook and Redwood.

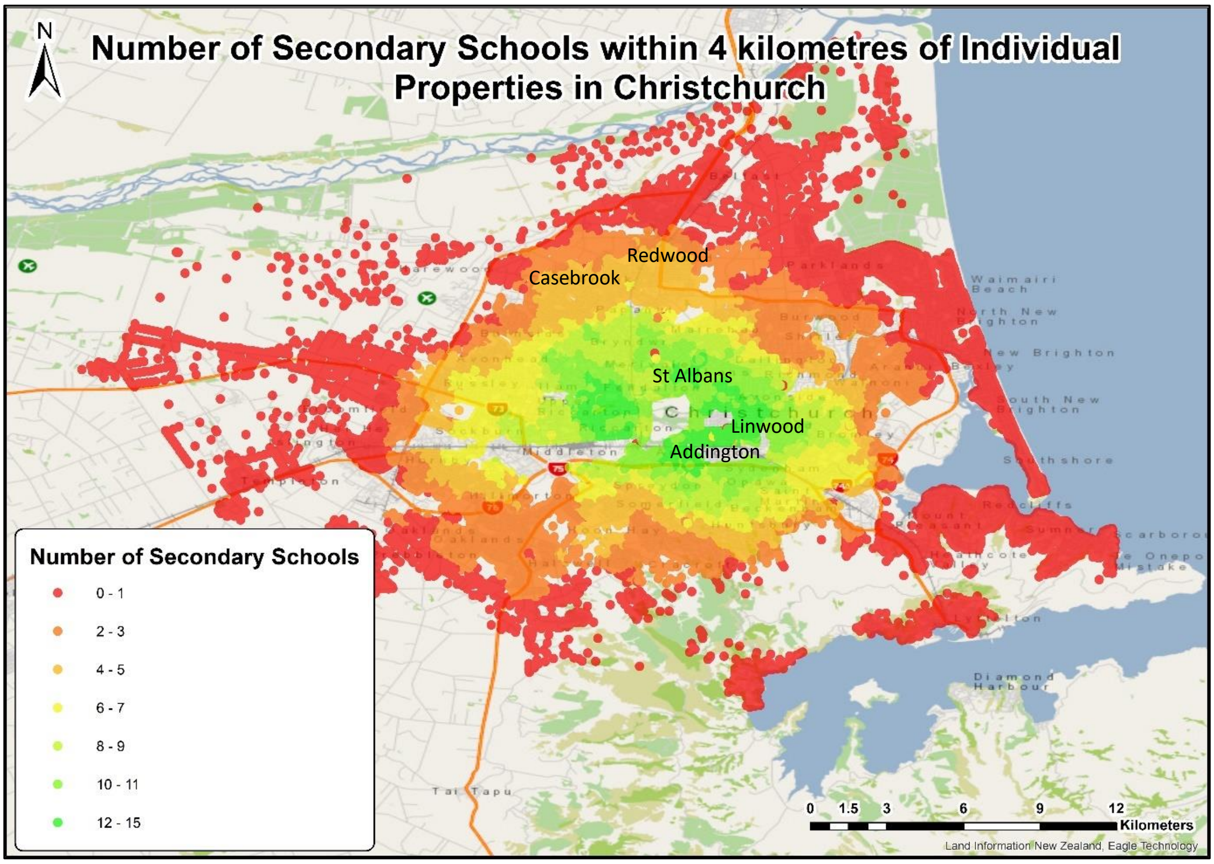

Figure 5.2 Number of secondary schools within 4 kilometres of each property.

5.1.3 Tertiary Education

Tertiary education sites are spatially more condensed than primary and secondary school counterparts. According to Figure 5.3, the focal point of tertiary education sites is Hagley Park, with the highest relative accessible properties being around the area. Accessibility does not extend south to the same extent as primary and secondary schools. There are more overall accessible properties to the west of Hagley Park; however better accessible properties (11 to 16) extend further the east of Hagley Park reaching up to Bromley. An outlier in the sense that it is partially detached from the overall trend is Hei Hei and Broomfield, as they are serviced by tertiary education sites which are most likely due a concentration of tertiary education sites.

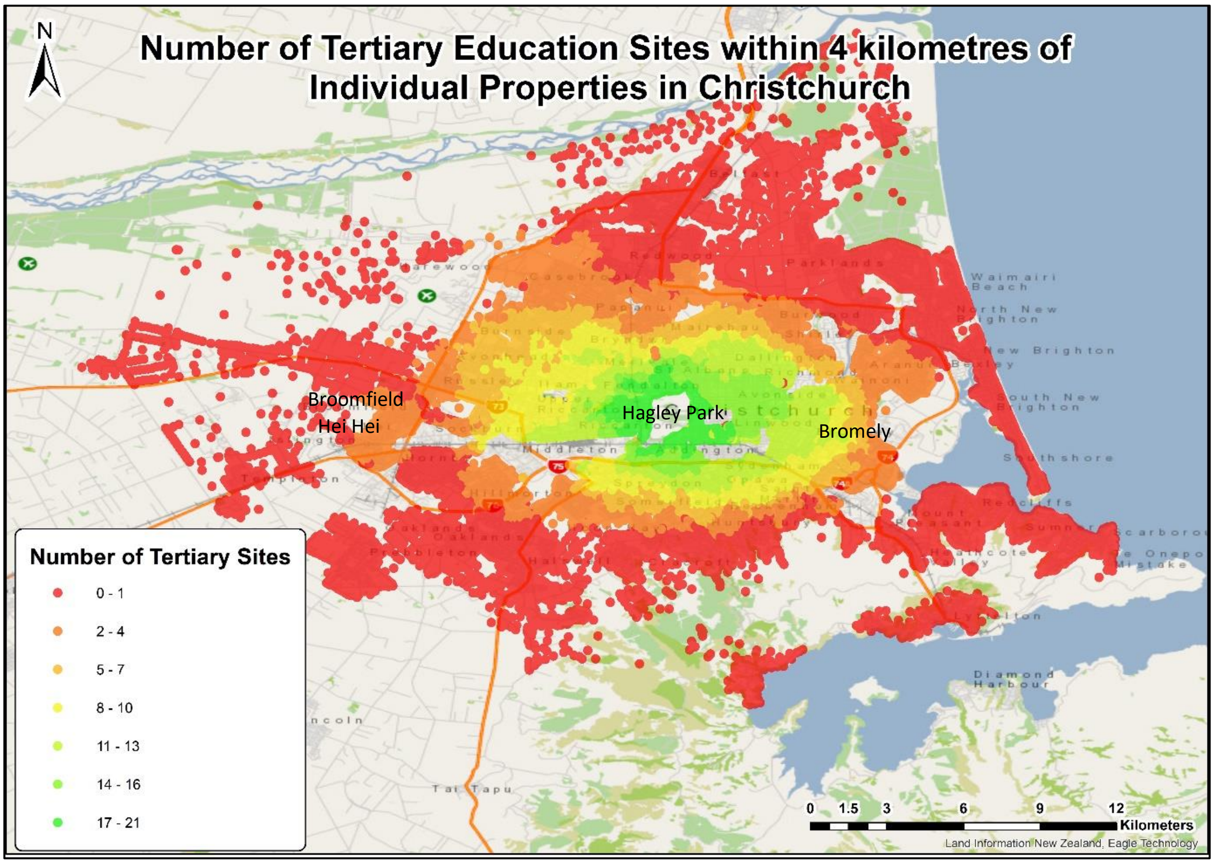

Figure 5.3 Number of tertiary education sites within 4 kilometres of each property.

5.1.4 Hospitals

Hospitals were the least abundant of the key destinations located in Christchurch, which is shown in the spatial extent of Figure 5.4. There are three areas with the greatest accessibility to hospitals, which are Riccarton, North Addington and South Addington. The CBD and suburbs surrounding the CBD are the most accessible areas to hospitals. Accessibility to hospitals extends further south than it does north and extends as far as Cracroft which is different compared to other key destination accessibility.

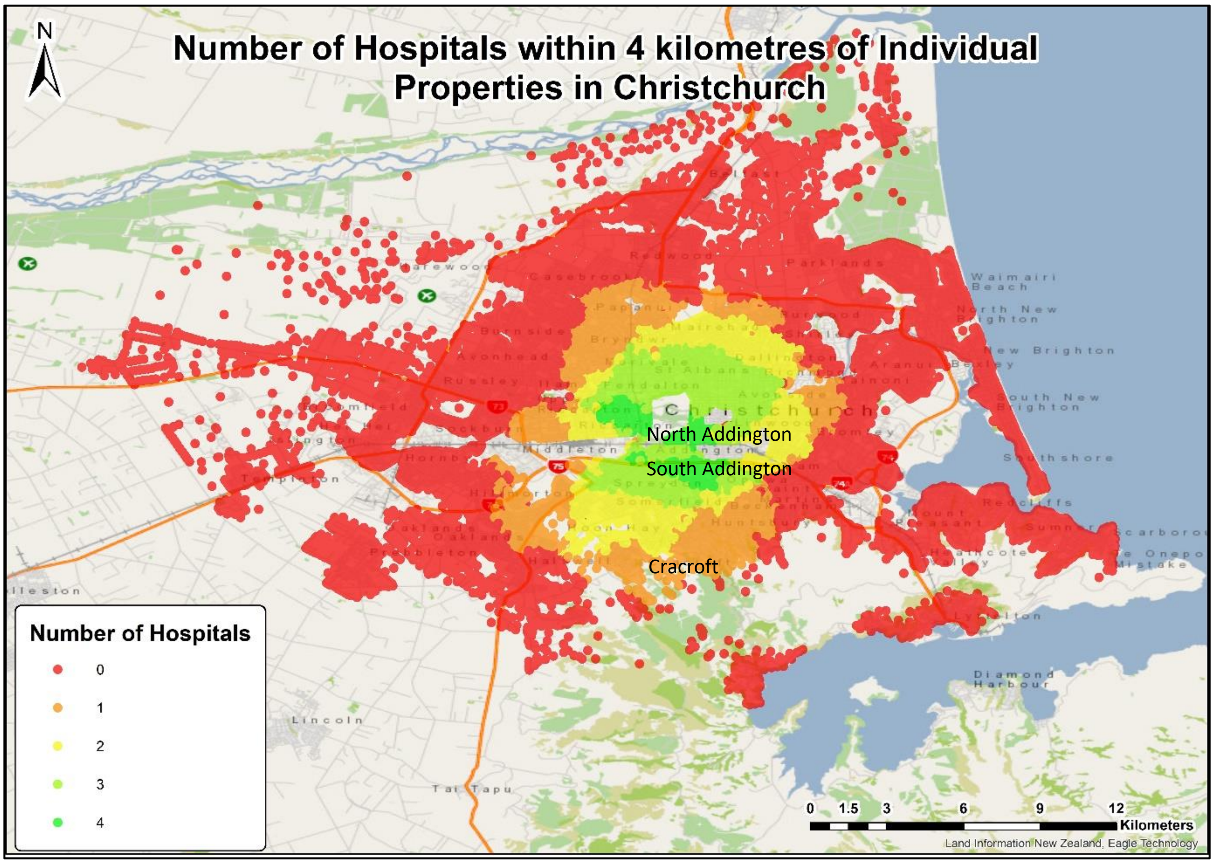

Figure 5.4 Number of hospitals within 4 kilometres of each property.

5.1.5 Medical Centres

Properties with the best access to medical centres are found within the CBD and between Fendalton and Merivale. Better accessibility extends further in the north-west of Christchurch. According to Figure 5.5, Redcliffs has a concentration of medical centres that raises it above the lowest category of relative accessibility like the surrounding areas. It is worth noting that New Brighton is also not in the lowest category of relative accessibility due to the number of medical centres across Christchurch.

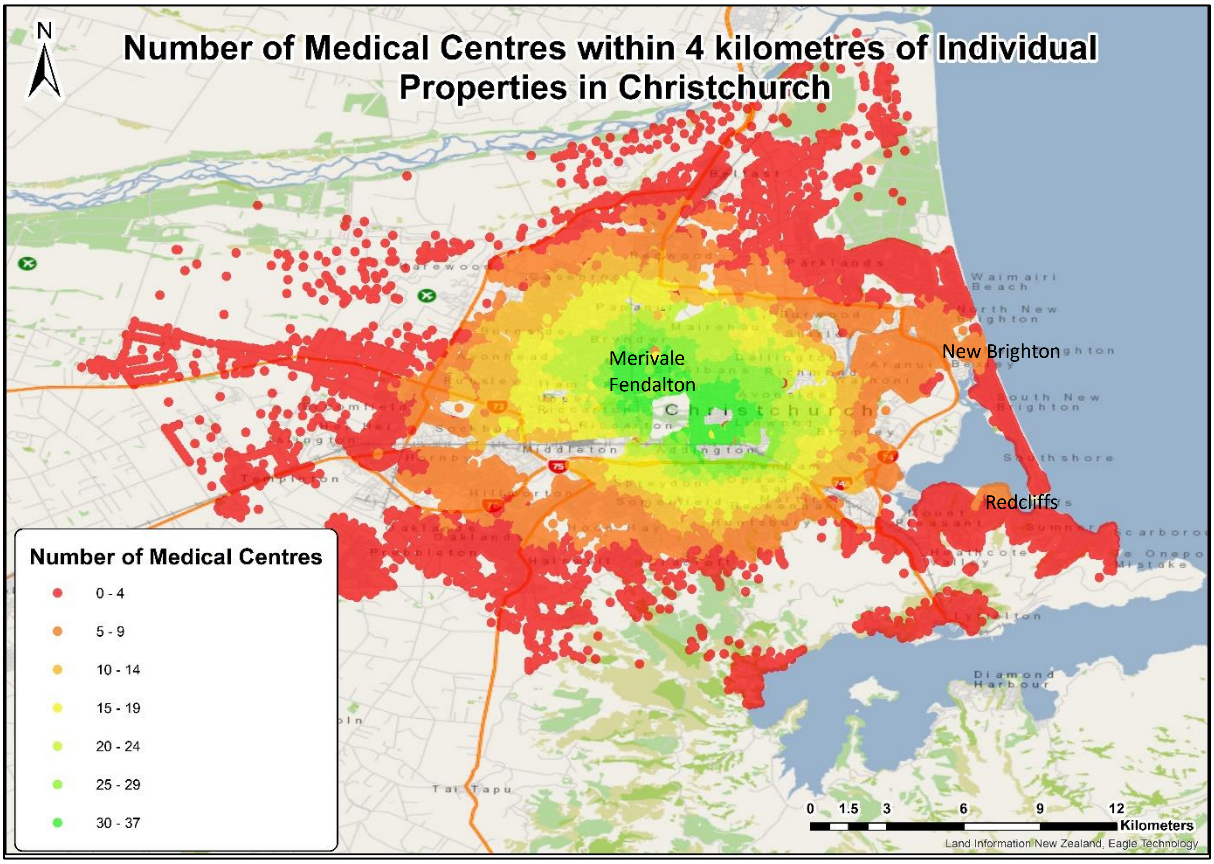

Figure 5.5 Number of medical centres within 4 kilometres of each property.

5.1.6 Supermarkets

Although the general trend of accessibility remains the same, compared to other key location accessibility assessments, supermarkets are located throughout Christchurch and not as clustered. Areas that are not considered typically inaccessible in other assessments are more accessible to supermarkets in certain cases. All examples can be found in Figure 5.6. The first example and most extreme is Redcliffs, Mount Pleasant and Sumner, where all suburbs are above the lowest accessibility category which means there is a concentration of supermarkets in the suburb. The second example is Hei Hei, Broomfield and Templeton where the area also has access to two or more supermarkets. This is most likely due to the surrounding industrial land use represented by the missing properties. It is common for large supermarkets to be developed on industrial land as it is relatively cheap. Redwood has higher accessibility than usual compared to other key destinations. The focal point for good accessibility is elongated extending from Sydenham to Papanui and Burnside.

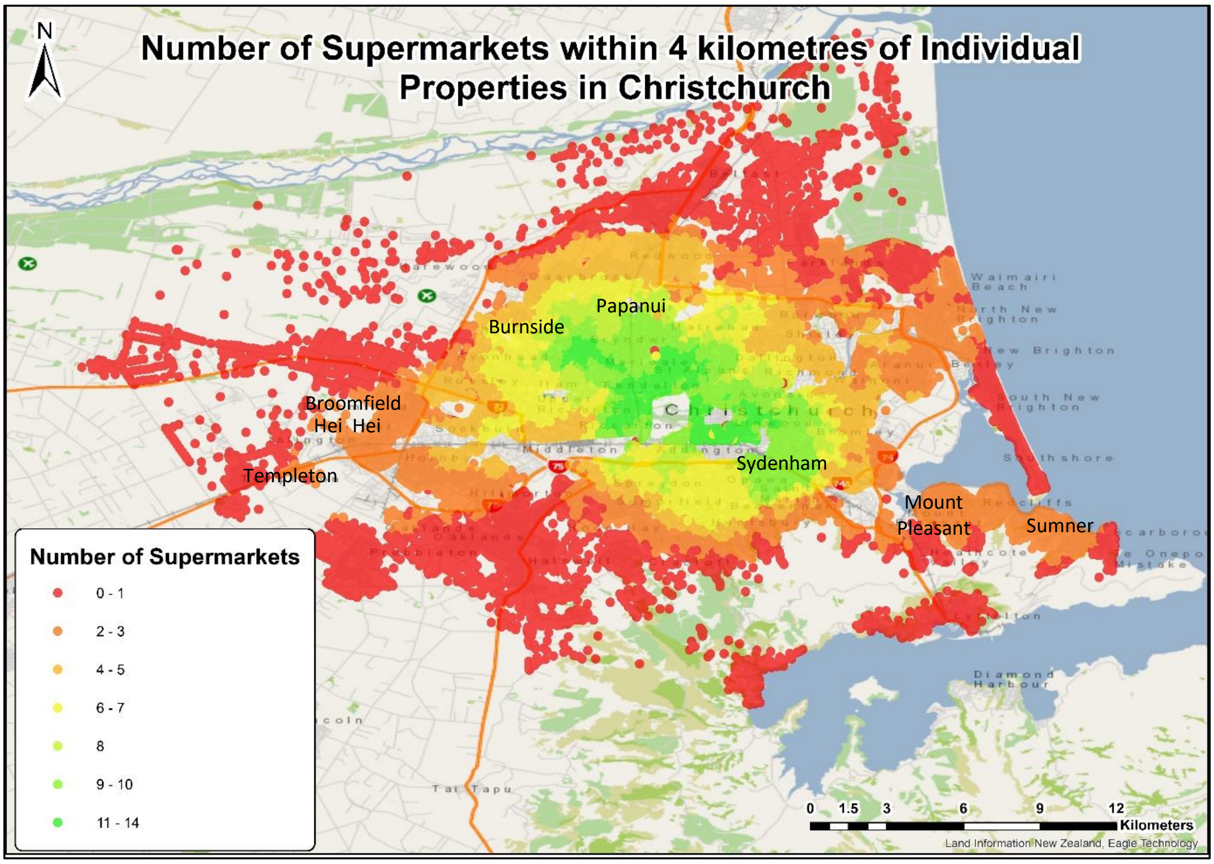

Figure 5.6 Number of supermarkets within 4 kilometres of each property.

5.1.7 Employment Opportunities

Employment opportunities, although conducted differently due to census area units being used, still follows the same trend as the previous accessibility assessments. The focal point for great accessibility is the CBD, and this appears to spread north-east reaching up to Papanui and Avonhead. This is likely due to the high concentration of businesses in those areas. Commercialised and industrial areas such as the CBD, Merivale and Addington have the greatest accessibility. There are no irregularities in Figure 5.7 most likely due to employment opportunities being derived from census area units which cover the entirety of Christchurch and employment becomes increasingly dense towards the CBD.

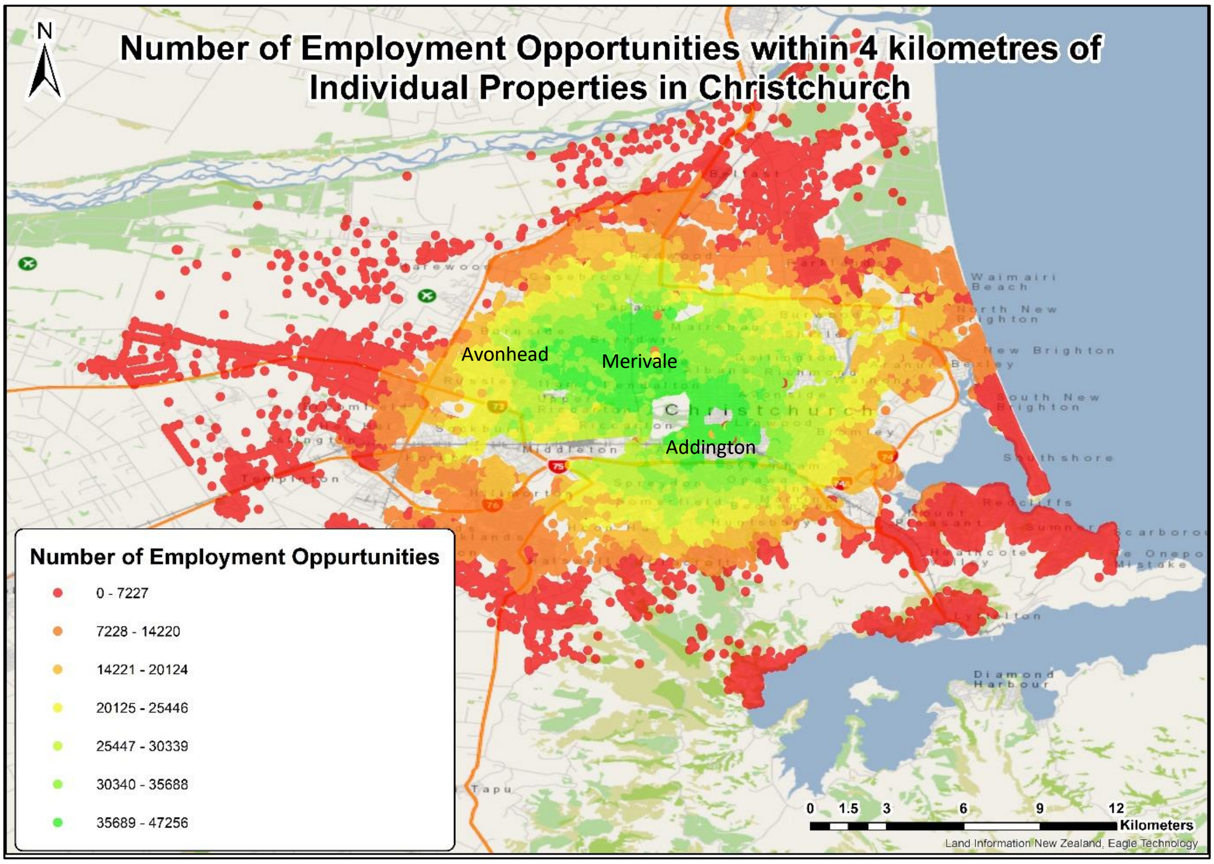

Figure 5.7 Number of employment opportunities within 4 kilometres of each property.

5.1.8 Weighted Accessibility

The combined weightings for each destination have been mapped in Figure 5.8 and ranges from values of 0 (low accessibility) to 3 (high accessibility). The spatial coverage in terms of great, good and fair accessibility in Figure 5.8 is greater than any of the individual accessibility assessments for key locations which is what to expect from a combined assessment. Moderate accessibility extends all the way to Templeton, New Brighton and Redcliffs, which is unusual considering the previous accessibility assessments. This is most likely due to relative accessibility being simplified, especially when categorising the key destination counts for each property.

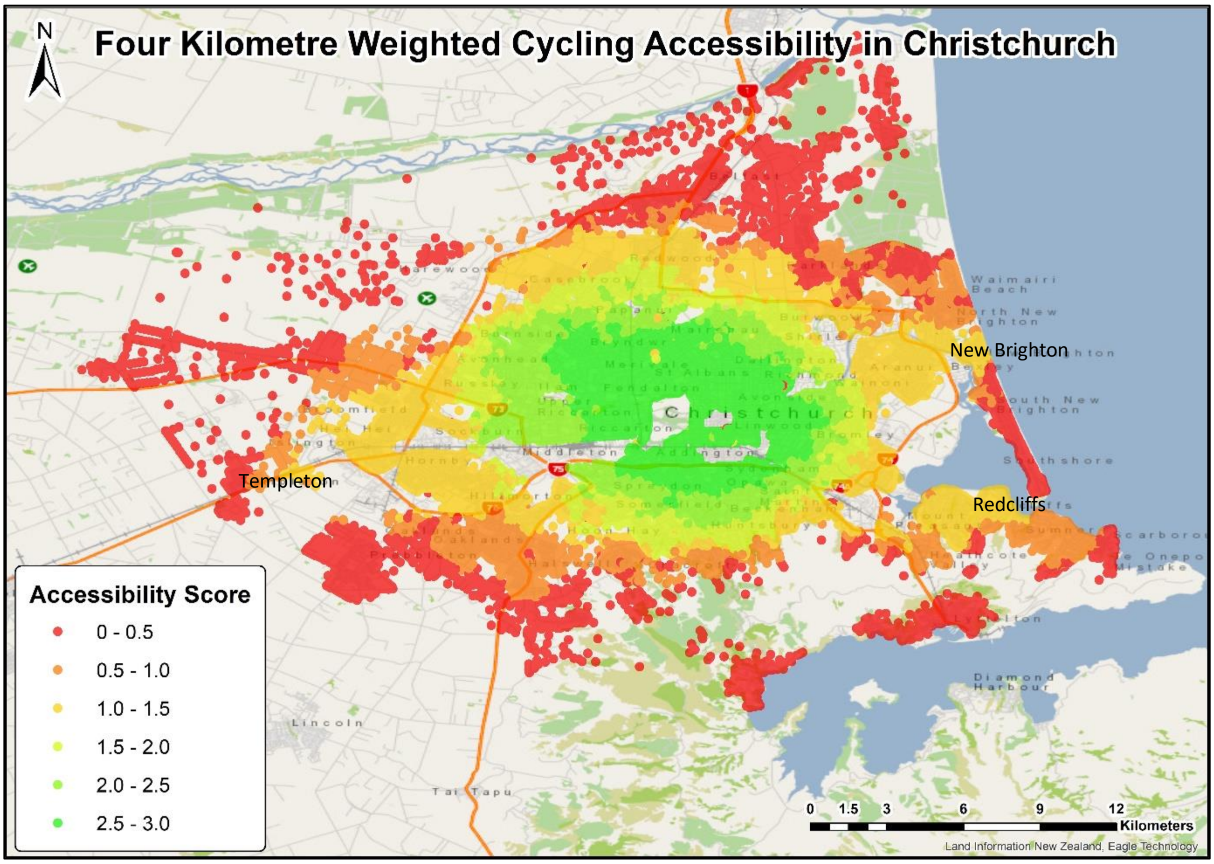

Figure 5.8 Weighted accessibility score for each property.

For the purpose of comparison, the accessibility assessment was averaged into census area units, which is shown in Figure 5.9. Cashmere and Rapaki have higher accessibility than expected due to all properties being mainly in the north of the respective area unit and no properties being located centrally. There is no transition where the airport resides from moderate to poor accessibility due to no properties located in the airport, thus not allowing a gradual transition in transport accessibility. It is evident that accessibility is highest in the CBD and becomes increasingly less accessible the further away a property is located.

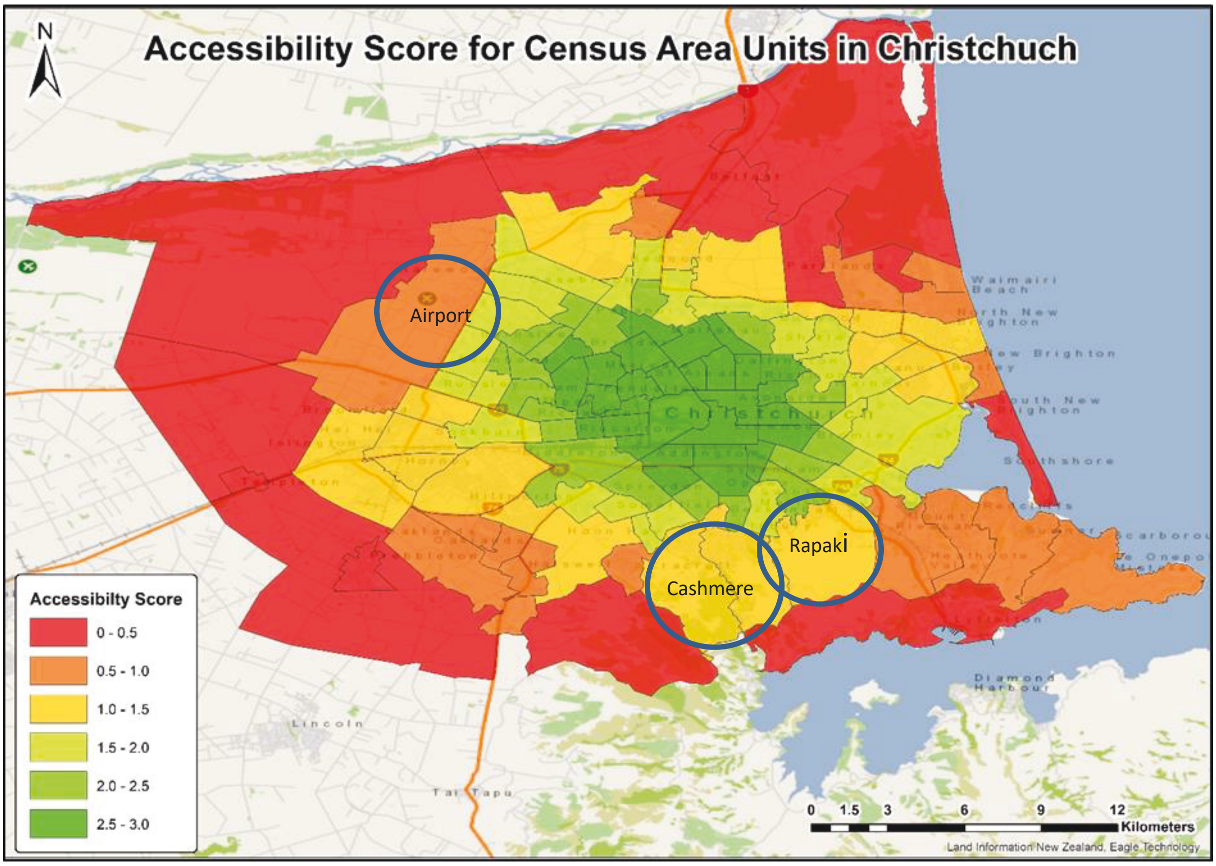

Figure 5.9 Average weighted accessibility score for census area units.

5.2 Annual Car Travel

The VKT data produced was originally conducted at a property scale; however, there were large variations in each of the points as annual VKT data is based on behaviour, which is less predictable than accessibility. This was resolved by scaling up the data through the use of both averaging and taking the median for each area unit. Both the mean and the median for VKT will be compared in order to determine which representation is more reliable regarding the effect of outliers found within the data. VKT will be critically analysed in its own regard, looking at spatial patterns and the differences in the data.

5.2.1 Median

The median is a reliable way of displaying VKT as it eliminates any extreme values found within the dataset as it takes the middle annual VKT value. The general pattern of median VKT roughly follows the same trend as accessibility with low VKT being within central Christchurch and becoming less accessible further away. However, there are notable outliers in the data according to Figure 5.10, such as low VKT values in Paparua and Trents-Ladbrooks on South-Western edge and high VKT values in the Avon-Loop, Edgeware, Sydenham and Waltham, close to the CBD. It is also important to note that although the map visually differentiates quite a lot, the largest difference in the annual VKT is 2,500 kilometres per year.

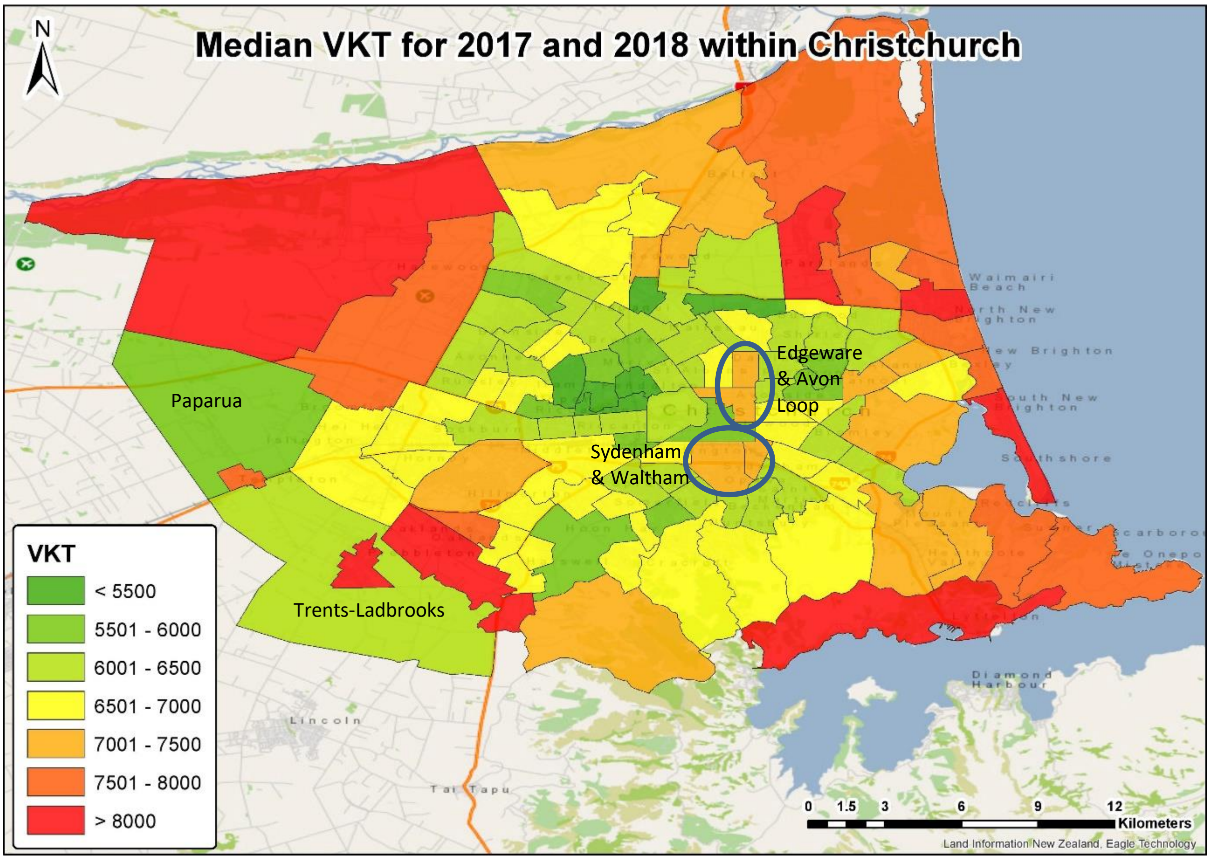

Figure 5.10 Median annual VKT for each census area unit.

5.2.2 Mean

The mean showed a different picture from the median, shown in Figure 5.11. Despite this, there is one outlier that stands out the most which are Hagley Park and Cathedral Square area units which are above 9,000 kilometres per year despite having the highest accessibility ratings. Mean annual VKT noticeably better represents accessibility than the median annual VKT for Paparua and Trents-Ladbrooks being in a higher relative VKT category. However, there is a greater degree of variability in the data compared to median annual VKT with examples including; Cashmere East, Rapaki, Addington, Sawyers Arms, Linwood and Aranui. The mean takes all values into account and is unable to negate in outliers, and for this reason the median is more reliable for comparison purposes. The mean also has higher overall VKT values than the median as legend categories are 1,000 kilometres higher than the median.

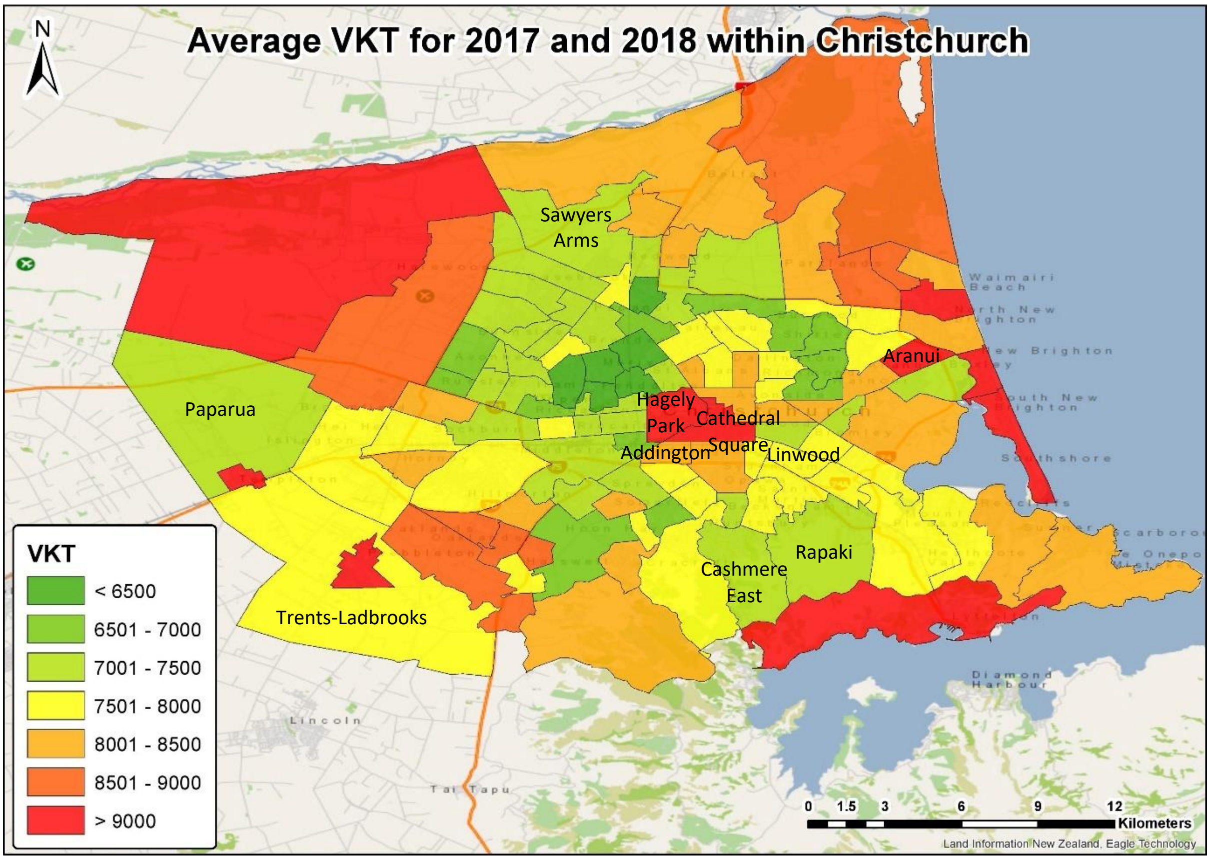

Figure 5.11 Average annual VKT for each census area unit.

With the cleaned data, a distribution graph was created showing the frequency of each of the range of VKT values, shown in Figure 5.12. What can be gathered is that most odometer readings are between 3,000 and 10,000 kilometres per year, peaking at 6,000 kilometres per year. There are a few readings under 1,000 kilometres which may be due to vehicles in storage or are not used for commuting purposes. At the other end of the spectrum, the odometer difference starts to plateau at 20,000 kilometres. However, there is still a significant proportion of readings above 10,000 kilometres which is expected.

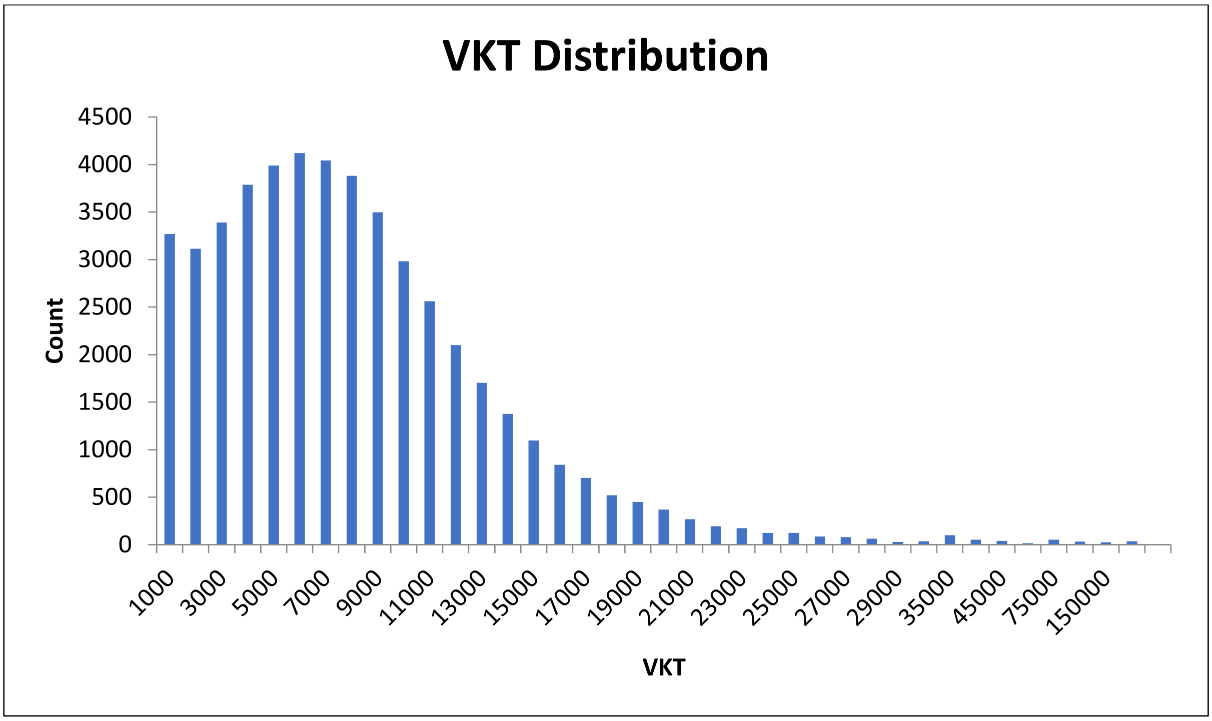

Figure 5.12 Count distribution of the used VKT spatial data.

5.3 Comparing Accessibility and Annual Car Travel

Despite both accessibility and VKT being assessed individually, the purpose of this dissertation is to compare the two to ultimately answer if people drive more or less in high and low accessible areas. Both accessibility and median annual VKT will be statistically compared to identify if there is a correlation.

From Figure 5.13, weighted accessibility and VKT have a weak to moderate negative correlation as shown by the R-squared value of 0.3939. As accessibility decreases, VKT increases to some extent. As Figure 5.13 demonstrates there are a few locations where VKT is considerably high where the accessibility score is below 0.25. The lowest VKT readings are found where the accessibility score is the highest; however, there are locations that have VKT values rising above the trendline despite high accessibility. These locations include Avon Loop, Sydenham, Edgeware, Waltham and Addington. The correlation between accessibility and VKT is not exceptionally strong but is enough to show a correlation, nonetheless.

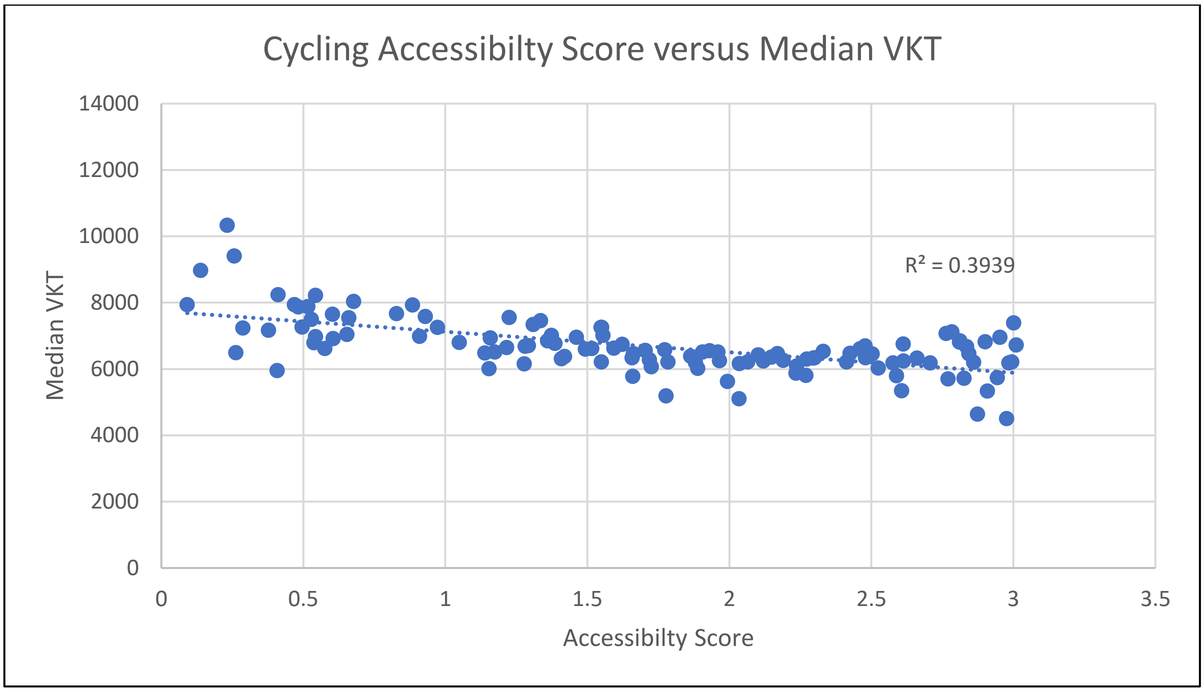

Figure 5.13 XY correlation between median annual VKT and the weighted accessibility score.

Based on accessibility results, VKT was expected to be lowest in the CBD however this was not the case. The lowest VKT was in the suburbs Ilam, Fendalton, Mairehau and Northcote. Illam and Fendalton have high accessibility only being slightly lower than the CBD and Mairehau, and Northcote is still above an accessibility rating of two. Despite the fact that most of the CBD and inner Christchurch were expected to have low VKT which was not the case especially for Avon-Loop, Edgeware, Sydenham and Waltham which fell well below expectations.

5.4 Count

Some outliers in the data could be explained through how many VKT points were spatially joined to each census area unit. As explained in section 5.22, there is a VKT readings have a high degree of variability in individual vehicles. Therefore, if an area unit has a low number of readings, which the mean is based on, then there is likely to be a high degree of uncertainty in the calculated mean. The number of VKT points joined to each area census unit is found in Figure 5.14. The two outliers on the southwestern fringe (Paparua and Trents-Ladbrooks) have relatively low join counts compared to the rest of the area units. However, Prebbleton, Mcleans Island and Lyttleton have the smallest number of points and show high VKT which is what is expected from the accessibility assessment found in Figure 5.8. Area units found close to the CBD including St Albans, Addington and Sydenham which showed VKT results contradicting accessibility cannot be explained with the number of points as these areas have a relatively high amount of points.

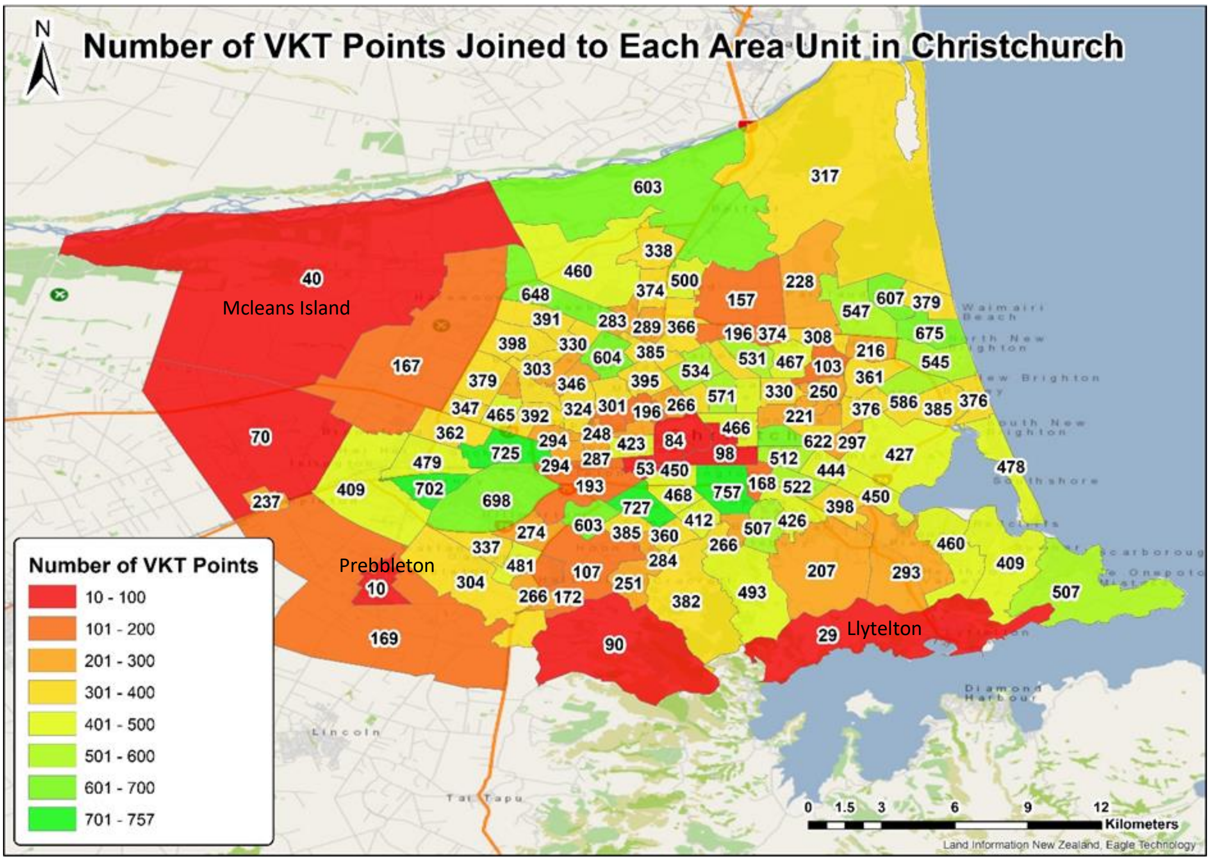

Figure 5.14 Join count of VKT points for each area unit.

According to Figure 5.15, the low join counts are found at both the high and low ends of the accessibility spectrum. This includes previously mentioned Lyttleton, Prebbleton and Mcleans Island, but also Kenedy's Bush and Paparua which are in the lowest join count category (<100) and in the lowest accessibility score (0 - 0.5). Reasons for this is that there are not a lot of residential properties. For example, Lyttleton is topographically constrained, Prebbleton is a small town, Mcleans Island is highly industrial, especially with quarrying, Kennedy's Bush is filled with recreational park and Paparua is a low-density rural area. As expected, Hagley Park and Cathedral Square have high accessibility, but low join counts due to very few people living in the area due to the land use. Hagley Park is a green space that is not suitable for building residential housing, and Cathedral Square is commercial land use. Another observation is excluding Lyttleton, Prebbleton and Mcleans Island, lower VKT values have slightly lower join counts, and higher VKT values have higher VKT values comparatively. If join counts below 100 were removed the correlation between accessibility and annual VKT would be reduced.

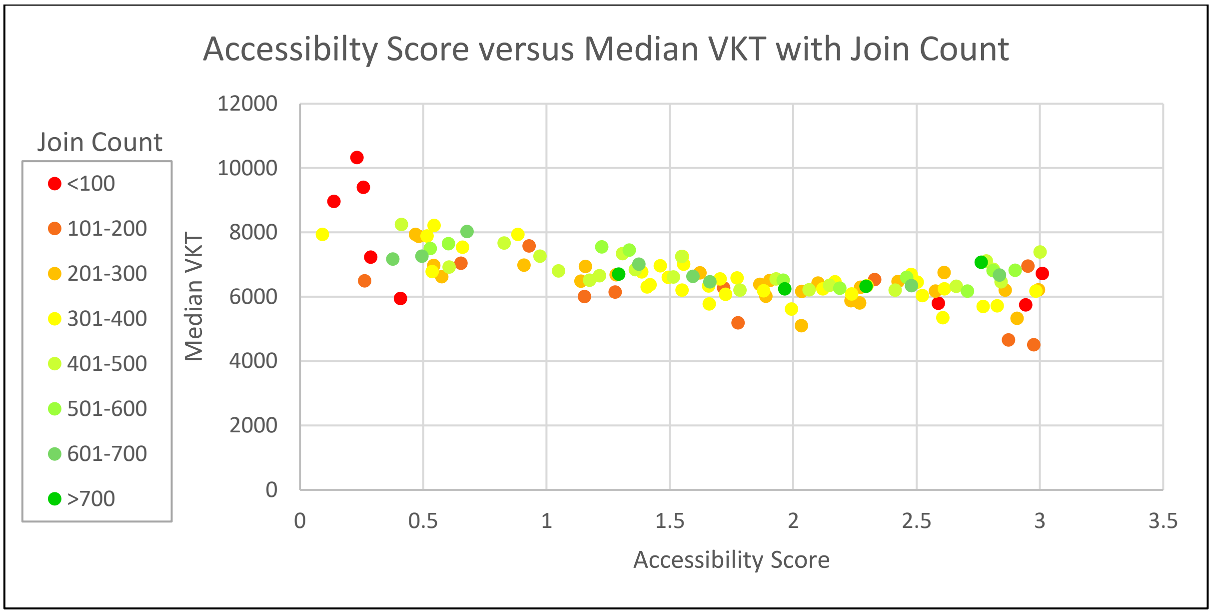

Figure 5.15 XY correlation between median annual VKT and the weighted accessibility score with join counts.

Join count is associated with accuracy due to a larger sample size within the area unit which demonstrates greater confidence in the results. From what has been shown in Figure 5.15 results, it appears as though in a general sense, higher VKT values have more points associated with them within each area unit.

5.5 Vehicle Ownership

Vehicle ownership was looked at spatially as per Figure 5.16. The logic behind this was to show the collective VKT regarding the population of each area unit. For example, if an area has a low median VKT result and another has a high median VKT the information may be misrepresented as the low VKT area might have high vehicle ownership and the high VKT are might have low vehicle ownership. This means that the total of the low median VKT will be higher than the area with high median VKT. Figure 5.17 shows that there is no correlation between VKT and car ownership due to some areas with lowest VKT having relatively high ownership and areas with high VKT also having relatively high ownership. Most area units in central Christchurch also have low vehicle ownership which does coincide with the accessibility results.

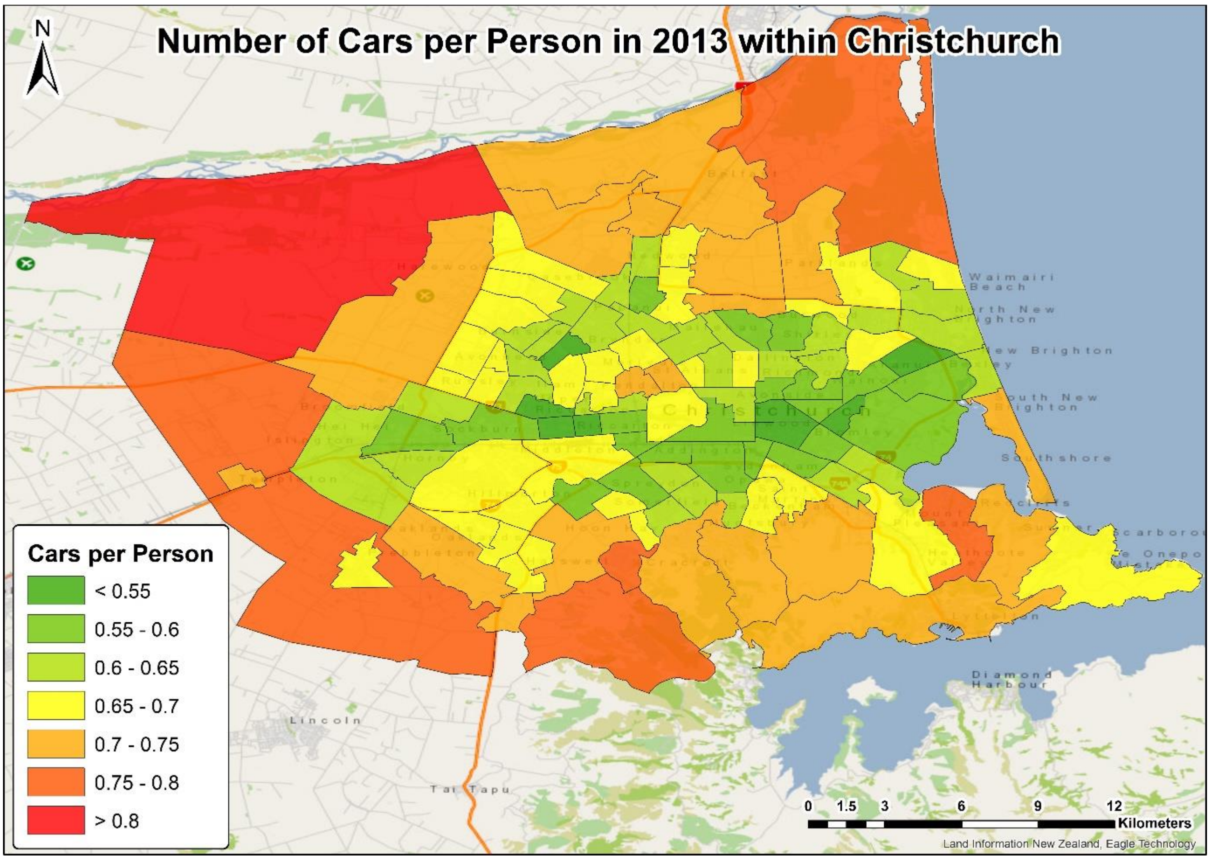

Figure 5.16 Vehicle ownership rates for each area unit.

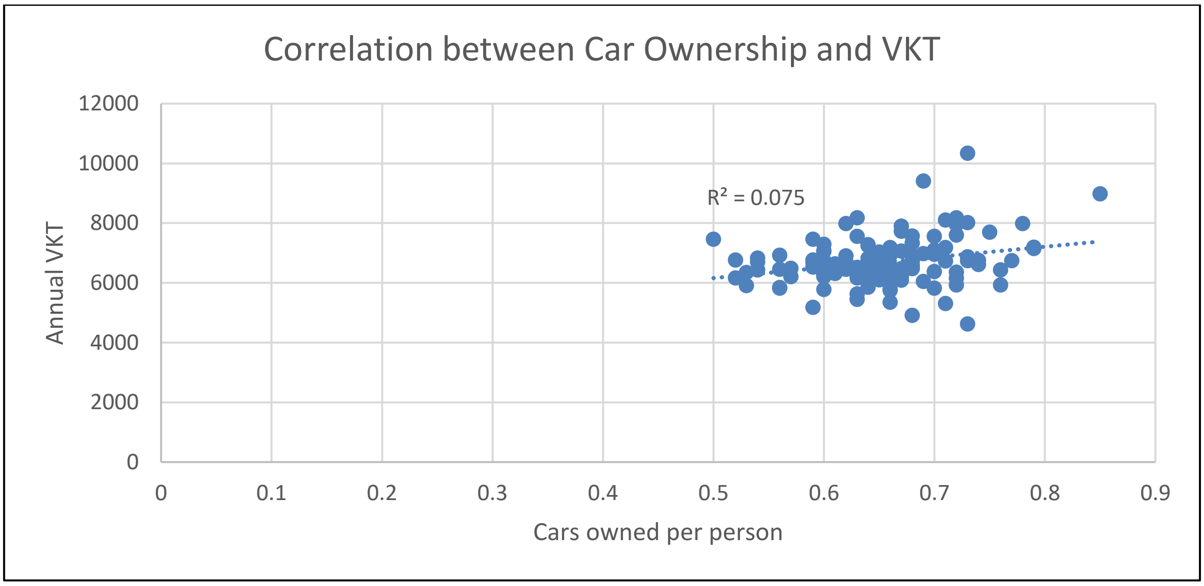

Figure 5.17 XY correlation between car ownership and the median annual VKT.

Due to the number of cars per person somewhat reflecting transport accessibility results vehicle ownership rates were applied to median VKT. As per Figure 5.18 below, anomalies that had low VKT in Figure 5.10, including Paparua and Trents-Ladbrooks on the southwestern edge have been somewhat normalised. Although it is still not what is expected from the accessibility assessment where both these areas should be in the lowest VKT category; however, it is still a more representative result of accessibility. High VKT values in the Avon-Loop, Edgeware, Sydenham and Waltham have been comparatively lowered especially in Sydenham and Waltham. Merivale located just above Hagley Park has comparatively had its VKT raised due to high vehicle ownership. The lowest VKT values remain in the Ilam and Fendalton area despite some high and low vehicle ownership in Figure 5.16 above. VKT for New Brighton has lowered due to low vehicle ownership rates being low. This change is more aligned with accessibility results. Sumner has had its annual VKT raised, resulting in being less representative of its accessibility score.

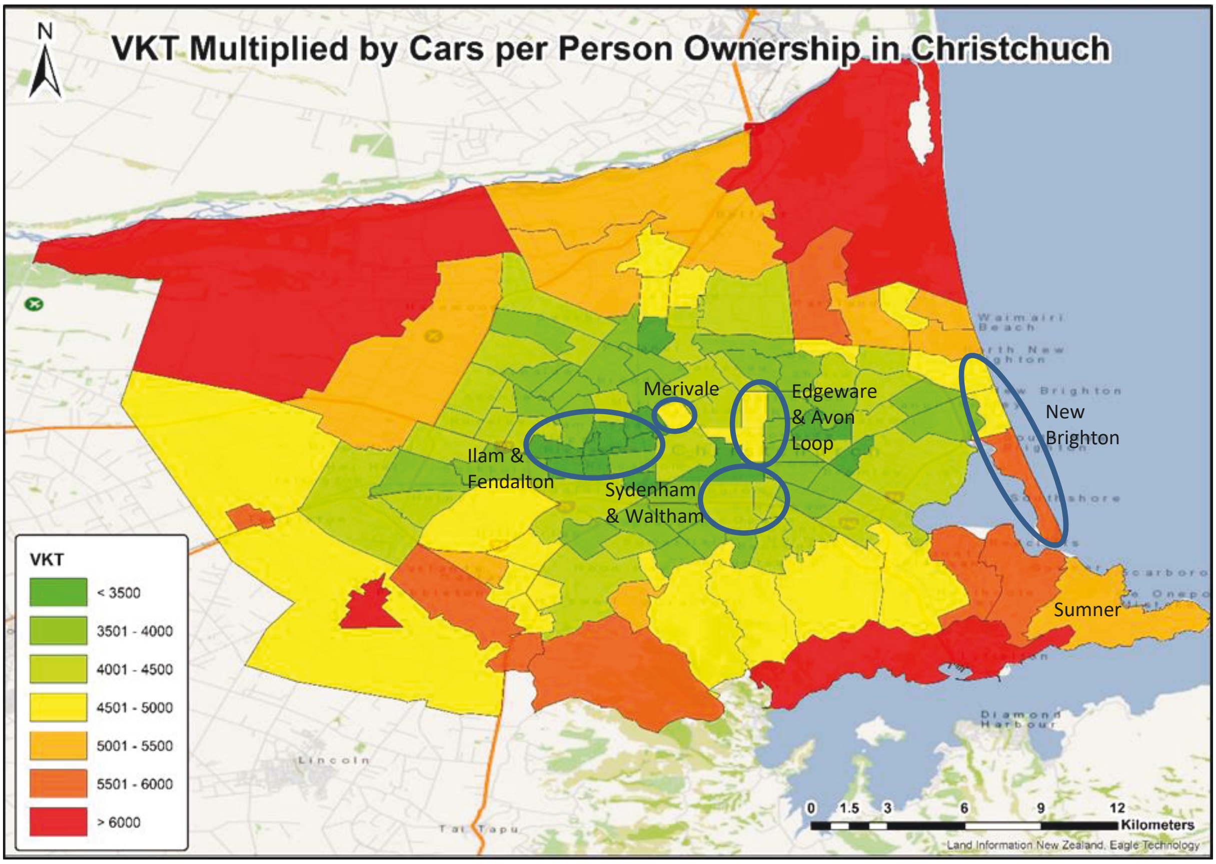

Figure 5.18 Car ownership rates per person combined with median annual VKT.

A scatter graph was created to statistically demonstrate the correlation between accessibility and the annual VKT per person. As shown in Figure 5.19, there is stronger correlation with the annual VKT per person with accessibility than with the standalone median annual VKT and accessibility (found in Figure 5.13). The correlation has an R squared value of 0.5584 compared to 0.3939. Overall the adjusted VKT is statistically a better fit than the unadjusted median VKT regarding accessibility.

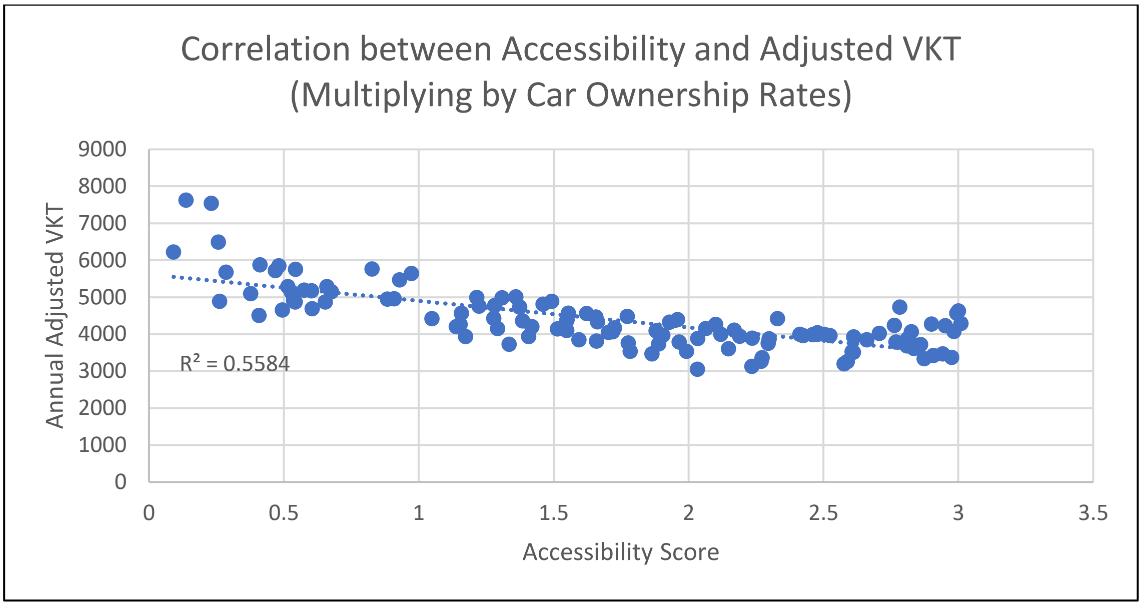

Figure 5.19 XY correlation between car ownership applied median annual VKT and the weighted accessibility score.

However, this does not go to say there is a strong correlation between the two, which should be expected from the accessibility results found in Figure 5.8. The results produced need to be looked at critically and discussed with other literature to understand why there are still outliers within the VKT analysis and how strong the correlation is comparatively.

5.6 Population Density

The population density of Christchurch was investigated to examine if densely populated areas have higher accessibility and if population density is a better predictor of VKT than accessibility. From the spatial analysis found in Figure 5.20 it can be concluded there is significant variation in central Christchurch and the fringe of Christchurch remains consistent with the exception of Templeton and Prebbleton due to their small area unit size and urban form. Hagley Park and Cathedral Square have exceptionally low density despite being in the CBD which is expected due to very limited residential properties due to the land use (open space and commercial). Both Middleton and Wigram area units also have significantly low density compared to surrounding area units. This is most likely due to the industrial nature, thus not accommodating many residents. Riccarton, Edgeware and Linwood are the most densely populated and are found close to the CBD. This is due to the residential nature of the area units and comparatively dense housing.

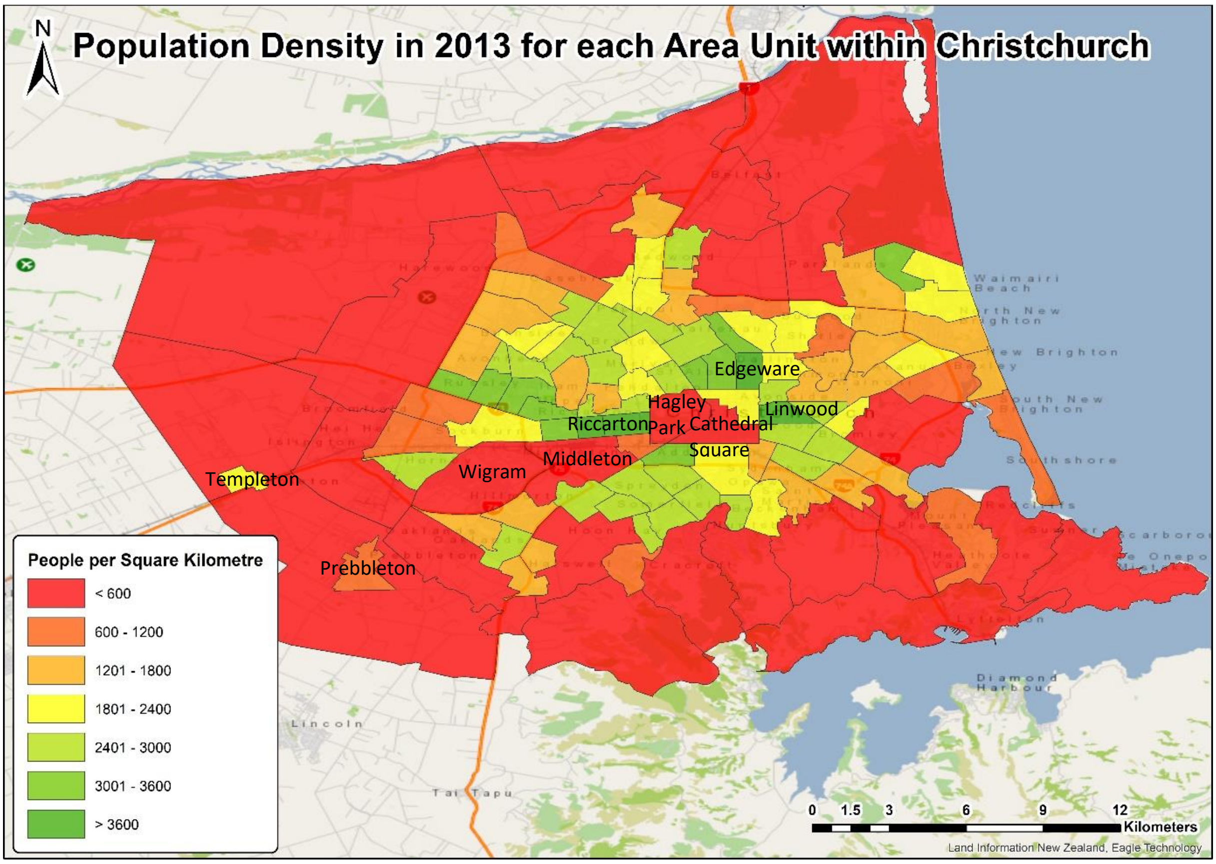

Figure 5.20 Population Density for each Area Unit within Christchurch.

A correlation between population density and accessibility was carried out to identify if people living in denser areas have better accessibility. It is expected that the more people there are living in an area, the more demand for facilities there is, therefore there should be more key locations in that area resulting in better accessibility. It also provides an indicator to see what proportion of the Christchurch population lives in accessible areas. From Figure 5.21, it can be established that there is a weak correlation between accessibility similar to accessibility and VKT showing a slightly weaker VKT value of 0.3439. There is one noticeable difference in Figure 5.21 compared to the correlation between accessibility and VKT in Figure 5.13, which is how dispersed the points are and how much they deviate from the trendline. This means that population density is not a precise indicator of accessibility. It can also be established that those living in dense areas do not necessarily have good accessibility meaning that there is a significant amount of the Christchurch population that has poor accessibility.

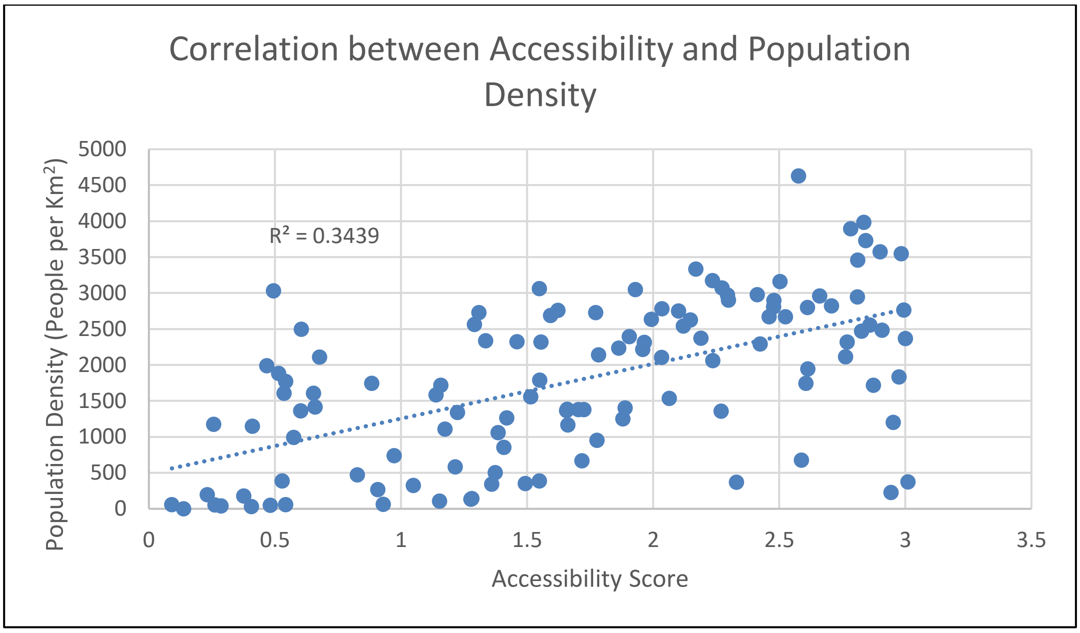

Figure 5.21 XY correlation between accessibility and population density.

It is possible that population density is a better indicator of annual VKT. The correlation between population density and VKT is found in Figure 5.22. From this, it can be established that there is no correlation between population density and VKT, and accessibility is a significantly better indicator for predicting annual VKT and annual VKT per person.

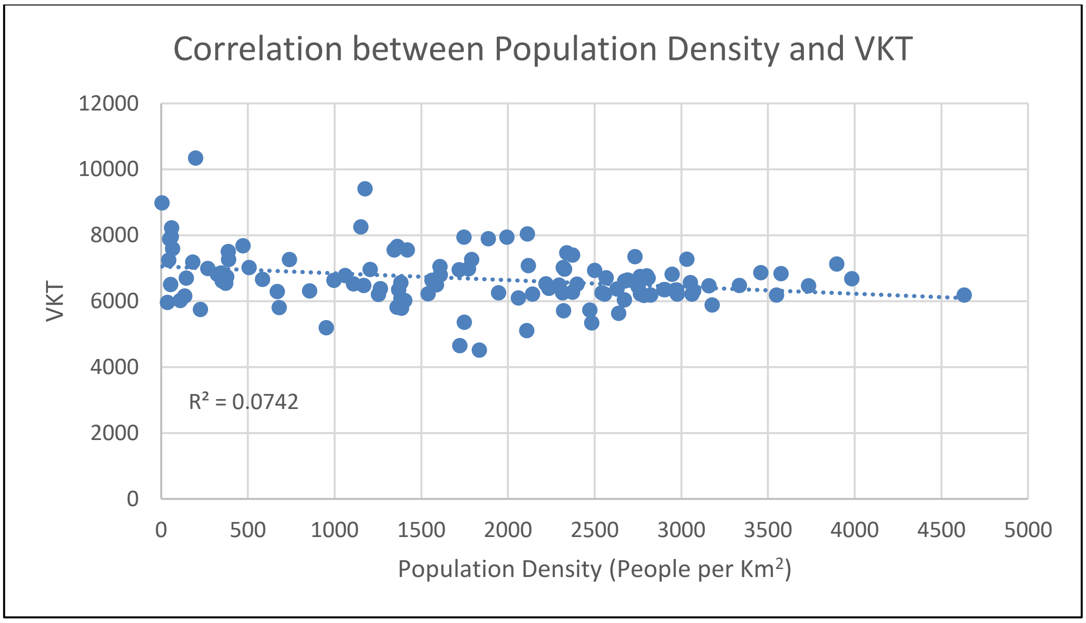

Figure 5.22 XY correlation between population density and VKT.

Chapter 6

Discussion

The purpose of this discussion is to compare the and contrast the results from this research with the reviewed literature, and to ultimately answer the research question of if people actually drive more or less in high and low accessible areas and to establish what this means for both policy and car orientated travel behaviour. Firstly, literature that looked at accessibility or VKT will be compared to the produced accessibility and both annual VKT results to identify similarities or differences. Secondly, literature that established a correlation between both accessibility and VKT will be compared to the produced results to establish how strong the correlation produced was and what it means. Thirdly, policy initiatives established within the literature will be contrasted with the produced results. Fourthly, the results produced and what this means for travel behaviour will be discussed. Lastly, key points will be summarised in relation to the overall research question to establish if people drive more on less based on their accessibility.

6.1 Accessibility

When comparing accessibility results to other literature, it is best to start with the work of Abley & Halden (2013), as the methodology for the accessibility assessment was simplified from their analysis. The accessibility assessment (all key locations except employment) produced by Abley & Halden (2013) in Figure 6.1 shows greater spatial coverage for good accessibility than the four-kilometre cycling accessibility assessment conducted for this dissertation found in Figure 5.8. This is an assessment for all modes and not limited by the four-kilometre service area buffer. Although good accessibility is present in more locations, it still originates from the CBD with poorer accessibility found on the outskirts of Christchurch. This is consistent with the results found in Figure 5.8.

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Figure 6.1 Accessibility scores for all transport modes. Retrieved from Abley & Halden (2013).

Employment opportunity accessibility was conducted separately in Abley & Halden (2013) and is found in Figure 6.2. Employment opportunities, although later combined to form a collective accessibility assessment was also produced in Figure 5.7 and will form the basis for comparison. When comparing the two figures, Figure 6.2 has less spatial coverage of good accessibility than the produced employment accessibility results in Figure 5.7. For example, New Brighton is relatively well employed, and Belfast is not as poorly accessible compared to the results produced by Abley & Halden (2013). Another notable difference is that Fendalton, Merivale, Bryndwr and Ilam have the same categorised accessibility score as the CBD in the produced assessment, something that is not apparent in Figure 6.2. A reason for this is that employment opportunities have moved away from the CBD post-earthquakes resulting in the CBD no longer being the sole source of plentiful employment opportunities.

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Figure 6.2 Employment accessibility scores for all transport modes. Retrieved from Abley & Halden (2013).

Another study that assessed accessibility explicitly cycling accessibility was Saghapour, Moridpour & Thompson (2016). Similar to the research conducted the accessibility assessment suggested that the number of bicycle trips should be high in the Melbourne CBD due to its high accessibility, however it was concluded by Saghapour, Moridpour & Thompson (2016) to not be the case as the bicycle trips in the CBD were not as high as some other Melbourne suburbs outside the CBD. Results from this study suggest a similar pattern substituting bicycle trips with VKT, for example the Riccarton area compared to the CBD. Despite the Riccarton area having lower accessibility than the CBD, it had a lower annual VKT.

Based on the results produced, they differ to that of Abley & Halden (2013), especially for all the key destinations (excluding employment). This was due to only active accessibility being examined. In contrast to this, it appears the accessibility assessment produced by Abley & Halden (2013) is dominated by the car which explains the limited variation in accessibility within central Christchurch. Relating this to travel, the car essentially has no bounds when it comes to travelling to key destinations (excluding employment) accessibility within Figure 6.1. People who use active transport modes are more sensitive to distance travelled. The only reason employment accessibility has more variation in the work of Abley & Halden (2013) is because the car is restricted by peak hour traffic increasing the time spent travelling, especially for those commuting further out. A potential improvement in the accessibility results produced in relation to how people travel is to factor in peak hour values; however, this is associated with time. Wagner (2003) did this effectively by converting the average peak speeds (which are lower than off-peak) to find the distance travelled in certain time intervals. If this was carried out the spatial coverage of the accessibility results would be theoretically be reduced. However active modes are not significantly affected by peak hours as they take up less space on the road and are not competing for space. Accessibility in this circumstance is associated with how far people are willing to travel not when people travel.

6.2 Annual Car Travel

The VKT distribution in the work of Yamamoto et al. (2018) located in Figure 6.3 showed a similar distribution than what is found in the results section in Figure 5.12. Although the distribution found in Figure 6.3, shows an overall higher calculated VKT (with the mode being 12,000 compared to 6,000) the pattern still remains the same.

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Figure 6.3 VKT distribution from French household survey responses. Retrieved from Yamamoto et al. (2018)

It could be argued that the standalone research conducted on VKT as part of this research is more accurate than the work of Yamamoto et al. (2018) due to sample size. 2,257 respondents reported there VKT in the qualitative data used by Yamamoto et al. (2018). The research conducted derived annual VKT from 49,320 vehicle odometer readings. This explains why the VKT distribution is more rounded and less variable than what is found in Figure 6.3. The VKT results conducted as part of this research are comparatively lower than the results in Yamamoto et al. (2018). A reason for this could be that the survey does not specifically look at metropolitan areas such as Christchurch, with Yamamoto et al. (2018) stating that people living in low-density areas drive more than those living within cities. Other potential factors could include people living in sprawled areas relying more on the car, or alternative transport modes have not been well established within France.

It is clear from Figure 5.14 that spatial distribution of the VKT points was distributed all over Christchurch with Hagley Park and the eastern edge having the lowest amount of points due to a lack of households within the areas. Although it is unspecified where the spatial locations of the households are in Yamamoto et al. (2018) it can be assumed that they were located across France which makes it comparable to the New Zealand Household Travel Survey. Based on this information the produced annual VKT results cannot be used and are not intended to be used for the rest of the country. However, it does provide an adequate understanding of travel behaviour within Christchurch using a large dataset.

6.3 Correlation Between VKT and Accessibility

The correlation between VKT and accessibility was expected to be strong as people will do what is most convenient and easiest to them, although this is often the car (Mandic et al., 2019). Although it is clear from the district plans of Greater Christchurch that Christchurch has been previously planned around the car with cycling provisions being incorporated. Based on the results, a correlation between cycling accessibility and VKT exists; however, the correlation is relatively weak only having an R squared value of 0.3939. When car ownership rates were applied to determine the VKT per person the R squared value improved to 0.5584. The R squared value represents the goodness-of-fit in linear regression models essentially being numerical way of showing how well the data fits the trend. Therefore, a high R squared value is associated with a stronger correlation between the two X and Y variables and vice versa. In Yamamoto (2018) it was stated that studies using regression models comparing VKT to gasoline consumption, vehicle emissions, and road accident exposure, had an R squared value ranging between 0.11 and 0.17. These values are much lower than the ones found in the results which show a significantly better goodness-to-fit. It can be gathered that comparative to these studies; accessibility is a relatively strong indicator of predicting VKT even without the applied car ownership values.

Another study that looked at R squared values is Kockelman (1997), specifically conducting correlations between VMT (separated into work and non-work), accessibility, car ownership and vehicle choice variables. Results from the study are summarised in Table 6.1 below:

Table 6.1 Correlations between relevant variables. Derived from Kockelman (1997).

Variable 1	Variable 2	R Squared Value
VMT (Work-Related Trips)	Accessibility	-0.31
VMT (Non-Work Related Trips)	Accessibility	-0.35
VMT (Work-Related Trips)	Car Ownership	0.56
VMT (Non-Work Related Trips)	Car Ownership	0.51
Walk/Bike Choice	Accessibility	0.22
Private Vehicle Choice	Accessibility	-0.036

Both R squared values in this research regarding annual VKT and accessibility were negative. Comparing the R squared values from the work of Kockelman (1997), the R squared values for VMT and accessibility were 0.31 and 0.35, whereas results showed a correlation of 0.39 representing a slightly better fit. Car ownership showed a better correlation with VMT (0.51 and 0.56) in the work of Kockelman (1997), meaning that car ownership is a better indicator of VKT than accessibility. However, results disprove this as when car ownership was correlated with annual VKT in Figure 5.17, and it was concluded that there is no correlation. Therefore, car ownership is not a good indicator of accessibility. Kockelman (1997) did not correlate car ownership rates with accessibility to get annual VKT per person; therefore, it is uncertain if applying car ownership rates to their VMT results and preforming a correlation analysis with accessibility would improve the R squared value. Although it was proven to provide a better correlation in the results. Despite this, the produced R squared values of 0.39 and 0.56 are consistent with the work of Kockelman (1997) when comparing VKT with accessibility.

Kockelman (1997) concluded that accessibility is very strongly associated with vehicle use through VMT. This conclusion is the premise for the research question when establishing if people actually drive more or less in high and low accessible areas. Kockelman (1997) came to the stated conclusion using the statistical correlation between accessibility and VMT which is lower than the correlation produced in the results (0.31-0.35 compared to 0.39-0.56). Therefore, it should be concluded from the results produced that accessibility is strongly associated with annual VKT and even more so for annual VKT per person. Overall based on the correlation results produced, people do in fact drive less in accessible areas and more in poorly accessible areas. However, it is important to recognise that there are some areas where this correlation does not necessarily apply and could be drastically improved. This is something that should be investigated further through identify travel behaviour beyond annual VKT. It is also worth noting that if low join count values were removed the correlation would have been reduced. Although overall people in accessible areas drive less it is far from perfect and is very likely linked to factors beyond distance such as comfort and convenience which are not covered by this research.

When comparing the results to behaviour, Kockelman (1997) demonstrates that there is a weak correlation between a person's choice to walk or cycle and accessibility. Therefore, people located in an accessible area prefer to walk and cycle over using a private vehicle. However, the choice of using a private vehicle showed no correlation. Therefore, accessibility does not play a role in a person's choice to drive. However, based on VKT results and the established correlation with accessibility people in accessible areas do relatively drive less, however since this down to a person 'choice,' it is a matter of preference which can be addressed with a qualitative analysis. For example, some areas were identified to have high VKT despite having high accessibility, however variables indicating why this is can only be assumed without further investigation. Saghapour, Moridpour & Thompson (2016) found a similar pattern with a high number of bike trips located in the suburbs outside of the city which has the highest cycling accessibility, although this did not involve car use. Assumptions can be made such as the high VKT and highly accessible areas such as Edgeware and Avon Loop having cheap housing incentivising people to live there however people will still work and visit outside of the area or make long recreational trips frequently (e.g. for sporting activities or to visit friends and family). The same applies to the areas concluded to have low comparative VKT to surrounding areas despite having low accessibility such as Paparua and Trents-Ladbrooks. Assumptions can be made such as a higher percentage of people commuting within the area unit or trips are being made less frequently by combining them together due to the greater distance from key locations opposed to multiple trips being made. For example, if someone was close to key location, they may go more frequently contributing to more VKT over time compared to someone who makes one long trip visiting multiple key locations. However, without a qualitative analysis of areas of interest these cannot be concluded.

The qualitative analysis would need to consist of various questions to analysis peoples travel behaviour. These questions should be focused on vehicle use should be directed at; A) how often people travel to the key destinations used in the accessibility assessment, B) if there are any other destinations visited regularly besides the key destinations used, C) what trips account for the most distance travelled, D) what factors influence vehicle mode choice, and E) what factors would make it easier to use alternative modes. With this information, travel behaviour can be further explained beyond the identification of abnormal private vehicle use behaviour, by providing reasons for this behaviour that accessibility cannot answer. Ultimately the feedback from a qualitative assessment for areas of interest identified in the results (e.g. Paparua, Trents-Ladbrooks, Avon-Loop, Edgeware, Sydenham, Waltham and Merivale) would allow for specialised policy to be developed to improve active mode use. Based on the results improving accessibility should not be a transport policy focus for the areas within central Christchurch that have high VKT despite high accessibility.

6.4 Transport Policy

Abley & Halden (2013) stated that having an improved understanding of accessibility can guide policymakers to improve accessibility through the clarification of implicit policy and creating new explicit policy. Although based on the results of this research, active mode accessibility can be targeted by policymakers within Christchurch to reduce private vehicle use, although this should be done with caution. The results suggest that people overall drive less in accessible areas as there is a comparatively strong relationship between accessibility and annual VKT compared to other studies such as Kockelman (1997), spatially there were results that went against this trend having high accessibility and high annual VKT. Areas with low accessibility should be targeted by policy as overall VKT is lower in areas with high accessibility. Although in areas with already high accessibility (e.g. central Christchurch) it has been proven that improving accessibility through policy will be ineffective at reducing private vehicle use. It should also be noted that areas with low VKT and low accessibility may be evidence that there are better ways of reducing VKT aside from accessibility. If accessibility policy is to be used to reduce VKT in the low accessible and high VKT areas identified by this research, policies that could be used will be discussed

A policy suggested by Mandic et al. (2019) of maintaining a network of cycleways and connecting cities to suburban developments would have more of an impact on VKT than it would on accessibility based on the conducted research. This is due to the distance being used and not time, cycleways were not prioritised and the only benefit this would have on accessibility is through suburban links that eliminate the need to travel on typically inefficient, curved and spread out road networks found in suburban developments. Having a maintained cycle network would make travelling by bike more attractive which would potentially reduce VKT, although results suggest that people still make long trips despite living in areas with attractive cycling infrastructure which is shown by annual VKT values in high accessibility area within Central Christchurch (e.g. Avon-Loop, Edgeware, Sydenham and Waltham). This could be due to residents living far away from work and therefore are required to commute further despite employment opportunities in Figure 5.7 being relatively abundant. These areas could be investigated as part of future research as the employment data used shows where people work and what area units people commute to. In addition, behaviour can be further investigated can be conducted in the stated residential areas to better understand the area and to look at existing cycling infrastructure and monitor its current users which is a good indicator of behaviour associated with cycling infrastructure.

Accessibility to schools has explicitly been covered in the accessibility assessment, and it was concluded that primary schools having a large spatial coverage and being one of the most abundant destinations alongside medical centres. Secondary schools are less abundant and have less coverage. Sullivan & O'Fallon (2010) looked at accessibility to schools in more detail using travel data from the household travel survey which concluded that the highest 1 percent of trips for school children is 7 kilometres for cycling and 5.1 kilometres for walking (2.9 kilometres for primary schools) and secondary school-aged children travel further. Results suggest that four kilometres is sufficient for primary schools as Harewood, Belfast and Sumner are the only areas that have poor access to primary schools. Secondary schools show a similar pattern just with the addition of New Brighton being inaccessible. However, Sullivan & O'Fallon (2010) stated that secondary school children are willing to travel further which would improve accessibility coverage in Figure 5.2. Any school orientated accessibility policy such as 'safe routes' suggested Mandic et al. (2019) would need to target areas with poor accessibility to schools as identified in Figures 5.1 and 5.2.

The encouragement of high-density development through land use policy would have an effect on population density. If higher density development was favoured, the accessibility assessment found in Figure 5.8 can be used as an indicator of where this development should occur. Ideally high-density development should be focused in areas with high accessibility to give more people better access to key locations. In addition, areas with high VKT and high accessibility such as Avon-Loop, Edgeware, Sydenham and Waltham should be targeted for high-density development. High-density development reduces car reliance and shows greater numbers of people walking, cycling and using public transport to ultimately spend less time commuting and reducing car use in general (Bentanzo, 2007). This was not the case however so it is uncertain that despite intensifying these areas, results may still remain the same. To support this Kockelman (1997) concluded that accessibility is a far better predictor of VMT and mode choice than population density. Results proved Kockelman (1997) to be correct with the correlation between population density and annual VKT having no correlation with an R squared value of 0.0742. The population density was concluded to be a significantly better indicator of accessibility than it was of annual VKT. It is unlikely that increasing density will reduce annual VKT based on results. If it is to be pursued through transport policy initiatives, areas with high accessibility are favourable for development as accessibility is the best-tested way of predicting annual VKT.

Ultimately, the results produced from the accessibility and annual VKT assessment is encouraged to be used as a guide for policymakers targeting areas where accessibility is not responsible for high annual VKT through using policy not related to accessibility. Alternatively, accessibility policy should be encouraged in areas with low accessibility as overall results suggest that improving accessibility will reduce VKT to an extent as people in accessible areas drive less; however, this does not apply to all cases and should be done with caution. The analysis is a base for policymakers intended for identification purposes only reasons explaining results can only be assumed without further quantitative analysis.

6.5 Behaviour

Annual VKT and annual VKT per person for the purposes of this research was used as an indicator for behaviour in the sense that it shows how people are currently acting regarding private vehicle use. Policies such as the ones suggested by Mandic et al. (2019) can enable behavioural change but will take time to have any effect and can be counterintuitive as people may make up travel time elsewhere by saving time travelling to work. One theory suggests that a person's travel time budget on average is one hour per day where time saved from travel can be reinvested elsewhere in transportation which could explain urban sprawl and travel choices (Joly, 2004). Another theory supports this suggesting that the overall travel time budget is between 65 and 70 minutes within cities regardless of transport mode, concluding that time saved due to faster travel does not occur it is instead spent elsewhere (Newman & Kenworthy, 2015). This could explain why there are in some cases high VKT values in the CBD and within central Christchurch and why the correlation between VKT and accessibility was not as high as expected. In addition, the travel time budget theory suggests that since active modes generally require more time to travel, the car could be favoured as more trips can be made in less time; thus, less time is spent. It is also worth acknowledging that just because someone lives in an accessible does not suggest they utilise that accessibility by visiting destinations outside of a four-kilometre radius.

To be able to coherently understand the situation regarding behaviour, a quantitative analysis of outliers and any other areas of interest should be conducted. This can provide a better understanding of where, why and how often people travel to the destinations they do create a better understanding of behaviour and a deeper understanding than what VKT provides in terms of explaining behaviour and private vehicle use. Currently the VKT dataset offers information on what areas drive the most and shows behaviour at a surface level, through conveying the distance people drive on a yearly basis. Beyond this there is no explanation to why people use the car despite being in a low or high active mode accessible area. Assumptions can be and have been made such as the travel time budget theory supported by Newman & Kenworthy (2015) and Joly (2004); however this is not certain. There is an opportunity for further research to be conducted surveying individuals and households to explain why the VKT results turned out the way they did and why the correlation between accessibility and VKT was not as strong as it was thought to be before analysis based off the reviewed literature.

6.6 Summary of Discussion

The produced accessibility assessment is consistent with other literature and has more variation expected due to active transport modes limited range. The CBD in both the results produced and the literature has the highest accessibility ratings getting increasingly worse further away. The distribution of VKT was expected, although lower compared to other literature meaning Christchurch resident comparatively drive less. The correlations established in comparison to other literature suggest that there is a very strong relationship between both accessibility and both annual VKT and annual VKT per person. Overall people in accessible areas do drive less; however, there are areas where this is not the case which need to be critical of. A quantitative analysis of behaviour in areas identified to not follow the overall trend should be conducted. Results suggest that policies such as improving cycling infrastructure, creating ‘safe routes’ to schools and encouraging high-density development may be ineffective especially in areas with both high accessibility and annual VKT. However if they are to be applied it should be done in areas with high VKT and low accessibility although done with caution. Reasons for abnormal travel behaviour could be due to the travel time budget theory; however, without further research into why people drive nothing is certain.

Chapter 7

Conclusion

The purpose of this research was to establish a correlation between walking and cycling accessibility to identify if we actually drive more or less in accessible areas and to suggest what this means for both policy and car orientated travel behaviour. Research regarding accessibility has been well established both in New Zealand and Internationally and is predominately assessed spatially. Annual VKT research is limited with few authors exploring the topic. In terms of correlating both accessibility and VKT, there was no literature reviewed that investigated this spatially. It was concluded that there was a significant gap in the literature comparing both accessibility and VKT, providing the opportunity to investigate. In addition, results can be used to assess policy implications and demonstrate car use behaviour within Christchurch. Since cycling accessibility was the focus of the research, the method adopted for assessing accessibility was focused on analysing the number of key locations (primary schools, secondary schools, tertiary education, hospitals, medical centres, supermarkets and employment) accessible to each property in Christchurch within four kilometres travel distance. It was concluded that accessibility was greatest in the CBD and worst around the fringes of Christchurch. Annual VKT was produced using odometer readings and the median values for each area unit. Annual VKT results showed that there is a similar pattern to accessibility, however not all results aligned with some area units possessing high VKT despite high accessibility within the CBD and others having low VKT despite having low accessibility. The correlation between accessibility and annual VKT showed an R squared value of 0.3939, comparatively strong compared to other studies. When car ownership ratings were applied to annual VKT to represent the annual VKT per person the correlation was improved, showing an R-squared value of 0.5584. Population density and car ownership were concluded to be poor indicators of annual VKT. Results were shown to be consistent with other studies. The produced accessibility and annual VKT results can be used by policymakers to target areas with high VKT where accessibility is not a concern. It would be beneficial to conduct a qualitative assessment in areas where the annual VKT results do not align with accessibility results to better understand travel behaviour.

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Appendix A

Weightings

A.1 Population

Table A.1 Population in each age group to be applied to weightings

Age Group	Population	Percentage
0-4	20925	0.06
5-9	19830	0.06
10-19	43296	0.13
20-24	27093	0.08
24-64	178608	0.53
65+	50379	0.15
Total	340131	1

A.2 Population Applied to Weightings

Table A.2 Applying population to weightings found within Abley & Halden (2013) for ages 0-4

Age Group 0-4		
Activity	Weighting	Adjusted_Weighting
Doctor	0.05	0.003076
Hospital	0	0
Primary School	0	0
Secondary School	0	0
Tertiary Education	0	0
Supermarket	0	0
Work	0	0

Table A.3 Applying population to weightings found within Abley & Halden (2013) for ages 5-9

Age Group 5-9		
Activity	Weighting	Adjusted_Weighting
Doctor	0.05	0.002915
Hospital	0.025	0.001458
Primary School	0.4	0.02332
Secondary School	0	0
Tertiary Education	0	0
Supermarket	0	0
Work	0	0

Table A.4 Applying population to weightings found within Abley & Halden (2013) for ages 10-19

Age Group 10-19		
Activity	Weighting	Adjusted_Weighting
Doctor	0.1	0.012729
Hospital	0.05	0.006365
Primary School	0.1	0.012729
Secondary School	0.38	0.048371
Tertiary Education	0.38	0.048371
Supermarket	0.16	0.020367
Work	0.38	0.048371

Table A.5 Applying population to weightings found within Abley & Halden (2013) for ages 20-24

Age Group 20-24		
Activity	Weighting	Adjusted_Weighting
Doctor	0.1	0.007965
Hospital	0.05	0.003983
Primary School	0	0
Secondary School	0	0
Tertiary Education	0.35	0.027879
Supermarket	0.15	0.011948
Work	0.55	0.04381

Table A.6 Applying population to weightings found within Abley & Halden (2013) for ages 25-64

Age Group 25-64		
Activity	Weighting	Adjusted_Weighting
Doctor	0.1	0.052512
Hospital	0.05	0.026256
Primary School	0	0
Secondary School	0	0
Tertiary Education	0.25	0.131279
Supermarket	0.15	0.078767
Work	0.65	0.341325

Table A.7 Applying population to weightings found within Abley & Halden (2013) for ages 65+

Age Group 65+		
Activity	Weighting	Adjusted_Weighting
Doctor	0.05	0.007406
Hospital	0	0
Primary School	0	0
Secondary School	0	0
Tertiary Education	0.1	0.014812
Supermarket	0.025	0.003703
Work	0.2	0.029623

A.3 Final Weightings

Table A.8 Combined weightings for each age group for each key location and converted to a percentage

Activity	Final_Weighting	Percent_Weighting
Doctor	0.086603	0.086
Hospital	0.038061	0.038
Primary School	0.03605	0.036
Secondary School	0.048371	0.048
Tertiary Education	0.222341	0.22
Supermarket	0.114785	0.114
Work	0.463129	0.459
TOTAL	1.009339	1

A.4 Box and Whisker Graphs

A.4.1 Key Locations (Excluding Employment)

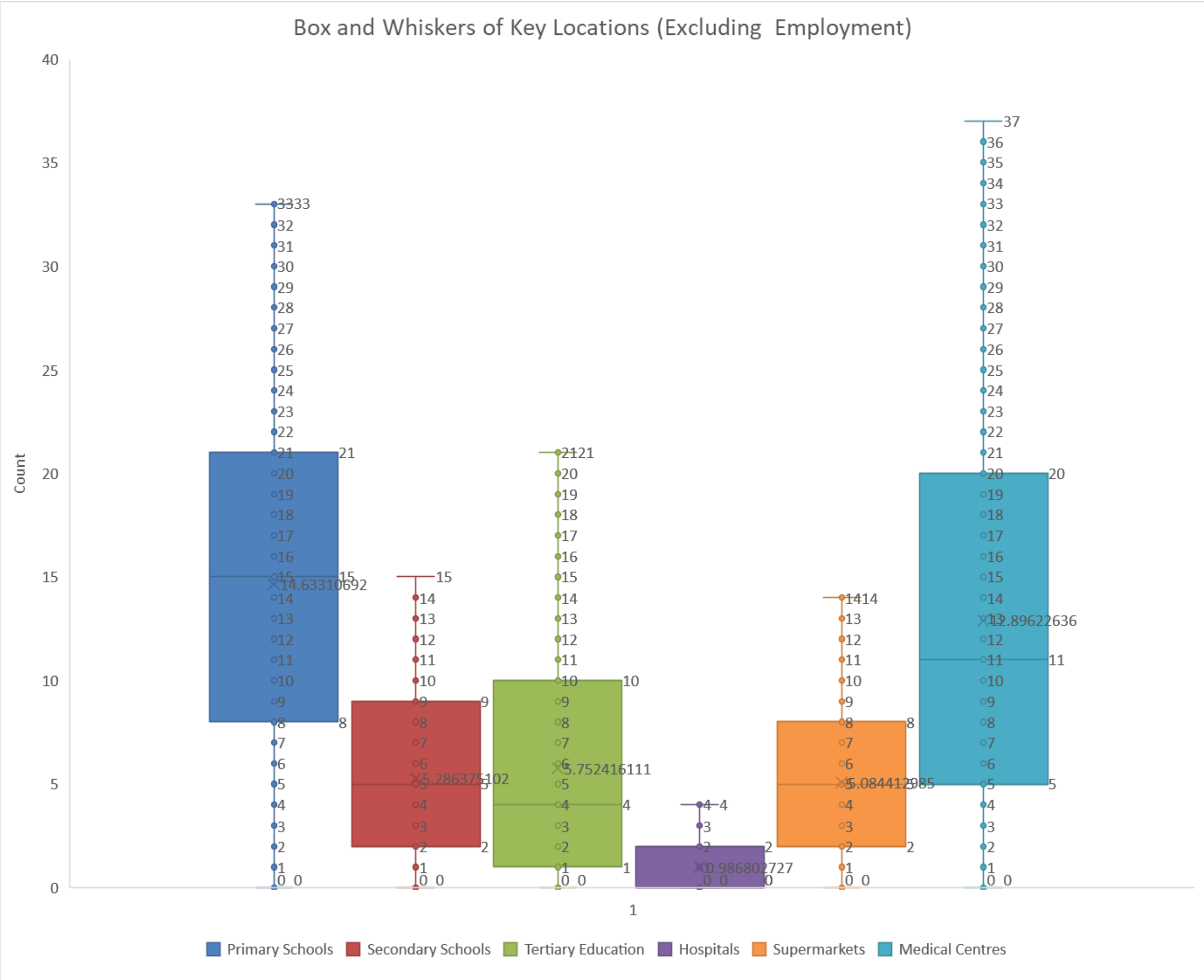

Figure A.1 Box and whisker graphs for key locations excluding employment to determine and rank relative accessibility

A.4.2 Employment

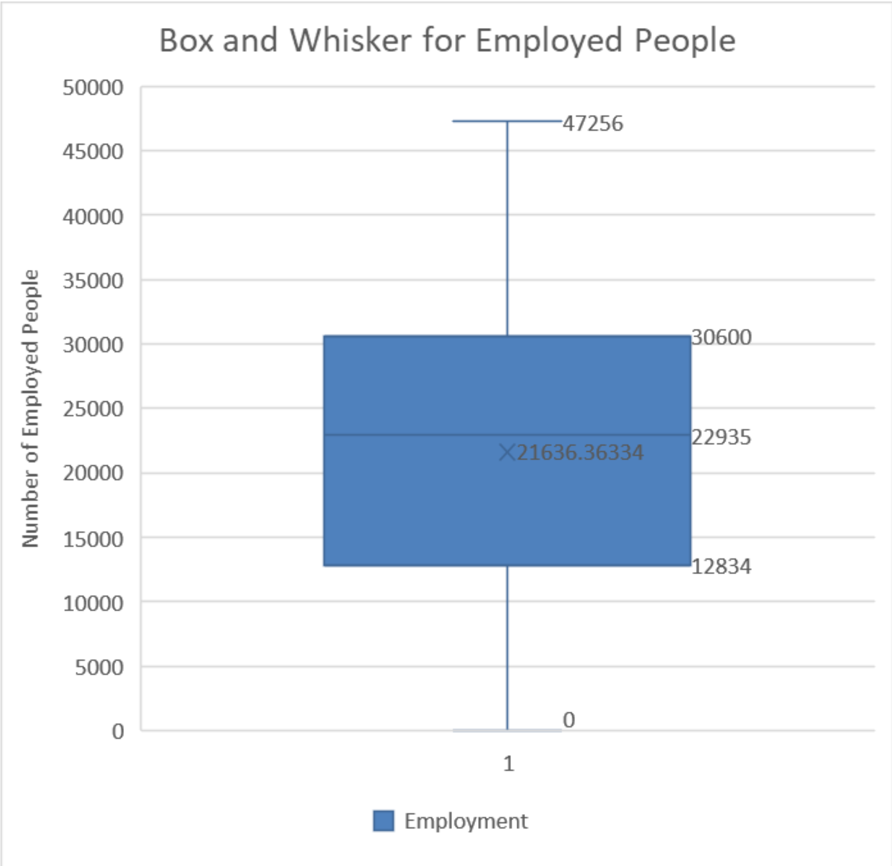

Figure A.2 Box and whisker graph employment to determine and rank relative accessibility

A.5 Table of Weightings for Relative Accessibility

Table A.9 Table summarising the relative accessibility scores derived from the box and whisker graphs

Location	*Inaccessible*	*Poor*	*Fair*	*Good*	*Great*
Primary School	0	<8	8-15	16-21	>21
Secondary School	0	<2	2-5	6-9	>9
Tertiary	0		1-4	5-10	>10
Hospital	0		1	2	>2
Medical Centre	0	<5	5-11	12-20	>20
Supermarket	0	<2	2-5	6-8	>8
Work	0	<12834	12834-22935	22936-30600	>30601
SCORE	**0**	**1**	**2**	**3**	**4**

Appendix B

Area Unit Names

B.1 Full Extent

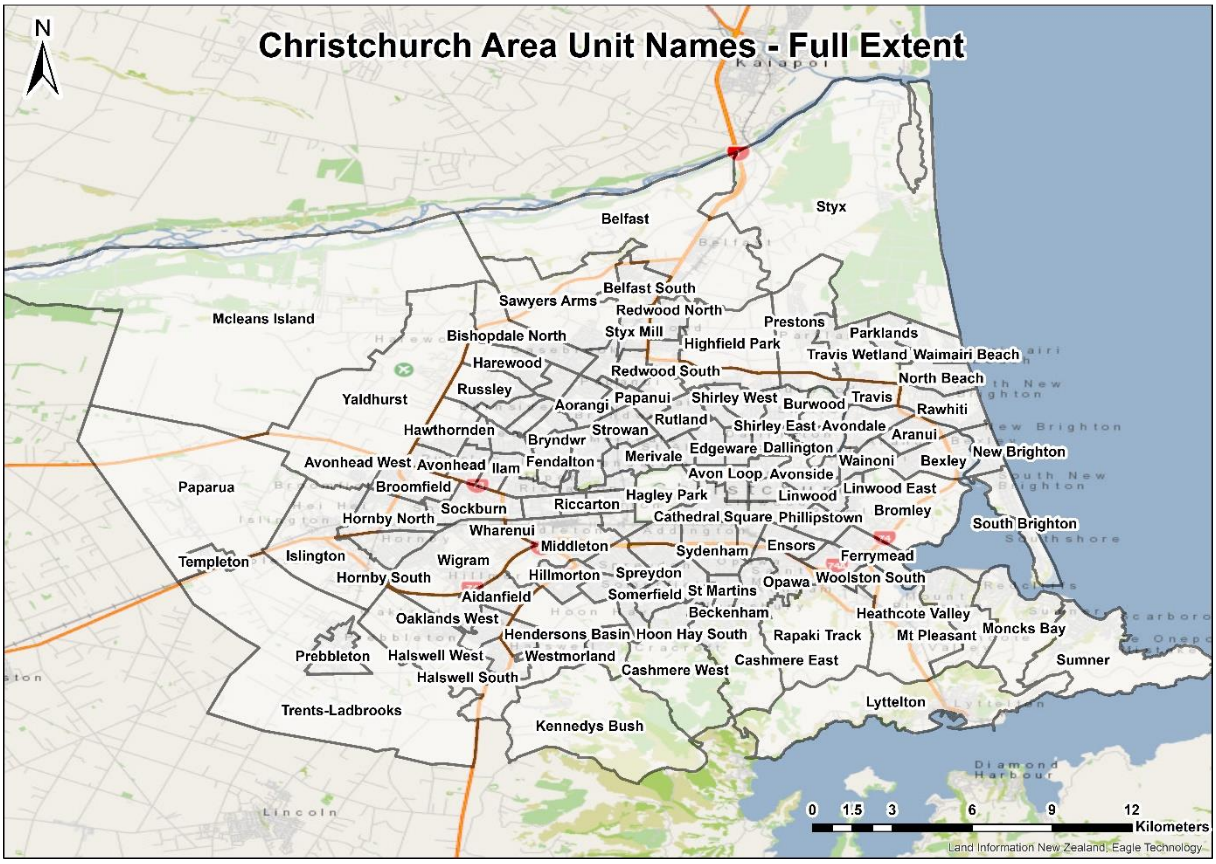

Figure B.1 Area unit names for all of Christchurch

B.2 Central

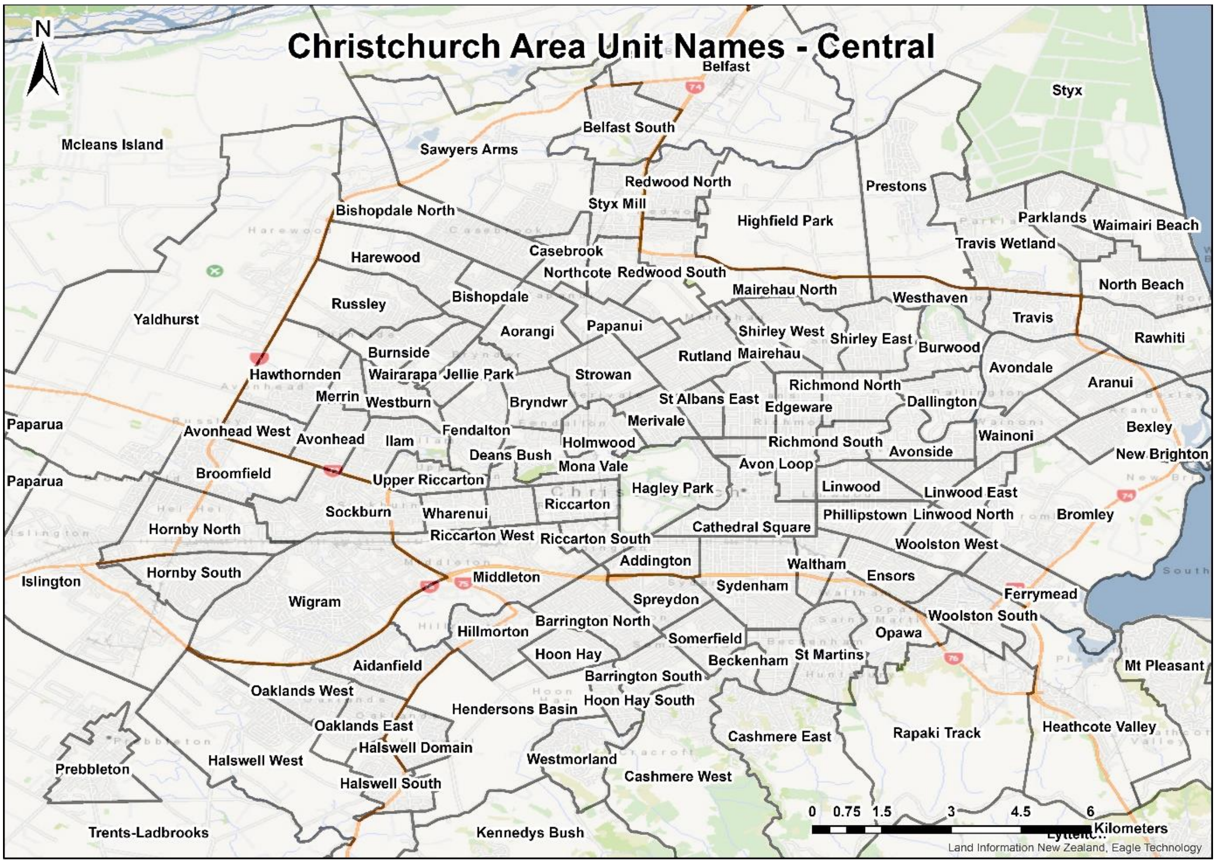

Figure B.2 Area unit names for central Christchurch